Final Report

SPACE SHUTTLE PROPULSION SYSTEMS ON-BOARD CHECKOUT AND MONITORING SYSTEM DEVELOPMENT STUDY

VOLUME III
OCMS CRITERIA AND CONCEPTS

March 1971

Contract NAS8-25619
DRL No. 187 Rev. A
Line Item No. 3

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

Prepared by

MARTIN MARIETTA
DENVER DIVISION

MCR-71-62

Final Report

SPACE SHUTTLE PROPULSION SYSTEMS ON-BOARD CHECKOUT AND MONITORING SYSTEM DEVELOPMENT STUDY

VOLUME III - OCMS CRITERIA AND CONCEPT

March 1971

Approved by

R. W. VandeKoppel
Program Manager

Contract NAS8-25619
DRL No. 187 Rev. A
Line Item No. 3

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MARTIN MARIETTA CORPORATION
Denver, Colorado 80201

FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS8-25619 "Space Shuttle Propulsion Systems On-board Checkout and Monitoring System Development Study," for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The report is comprised of four volumes:

- Volume I - Summary
- Volume II - Propulsion System Definition and Criteria
- Volume III - OCMS Criteria and Concept
- Volume IV - Appendices

CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

NOMENCLATURE

I. Definitions

BIT: A single binary digit. The smallest informational element of a digital system.

BUILT-IN-TEST EQUIPMENT (BITE): An integral part of a functional unit which serves to test and/or provide status on that functional unit, but does not participate in performing the unit's principle function

BYTE: A specified number of BITS.

CHECKOUT: The process of determining whether or not specified physical quantities or operations meet their prescribed criteria. The process can include such functions as data acquisition, processing, storage, display, stimulus generation, etc.

CONTROL: The act or process of initiating, regulating and/or terminating the operation and performance of a functional element in a prescribed manner.

CONTROLLER: A device which governs the state or performance of a particular functional element in a prescribed manner, e.g. engine controller.

DATA BUS: The transmission line(s) along which the system computer(s) communicate with the various Digital Interface Units, controllers, peripheral equipment, and other computers.

DATA COMPRESSION: The process of screening and selecting data such that only desired information is retained for further processing and/or storage.

DESIGN REFERENCE MODEL: The baseline configuration.

DIAGNOSIS: The determination of the state or condition of an element or parameter through evaluation of available data.

DIGITAL INTERFACE UNIT: An intermediary unit between the computer(s) and another device which formats that device's output for communication to a computer, and accepts and translates a computer's transmissions to the device.

FAULT ISOLATION: The processing of analyzing a malfunction or abnormality to the extent of determining which functional element is defective, where the functional element is ordinarily a Line Replaceable Unit.

NOMENCLATURE (Continued)

FUNCTIONAL ELEMENT: A unit which performs a characteristic action. Parts, components, assemblies, and subsystems are functional elements of increasing complexity.

GAS PATH ANALYSIS: An assessment of engine performance that is made through evaluation of a set of measured values of pressures, temperatures and/or flow rates.

GROUND SUPPORT EQUIPMENT: (for checkout and monitoring) That equipment, in addition to the onboard equipment, which is needed to accomplish the functions of checkout and monitoring.

LINE REPLACEABLE UNIT: A component or group of components that can, as a unit, be removed and replaced in the normal vehicle maintenance area. Such criteria as allowable replacement time spans and degree of complexity of post-replacement calibration form a basis for Line Replaceable Unit selection.

MAINTENANCE: Those functions and activities associated with restoring the vehicle to an operational condition between flights.

MEASUREMENT: A physical quantity or event whose magnitude or time of occurence is of significance.

MONITORING: Repetitive acquisition and evaluation of needed data.

POGO: An oscillatory instability resulting from a dynamic coupling between the fluid and structural elements of the vehicle.

PROCESSING: The manipulations and operations performed on data from the time and place it is acquired to the time and place it is used in its final form.

SELF CHECK: The process by which a functional element assesses its own operational integrity and readiness.

SENSOR: A functional element which responds to a physical quantity or event and converts that response to transmissible data which is proportional to the magnitude of the quantity or indicates occurence of the event.

SINGLE POINT FAILURE: A functional element whose inability to operate within prescribed limits would cause loss of vehicle, crew, and/or mission objectives.

STIMULUS: An excitation or forcing function which is applied from an external source at a prescribed place and time.

NOMENCLATURE (Continued)

TIMELINE: A representation of a sequential series of events which depicts the time of occurence and duration of each event.

TRANSDUCER: Same as sensor.

TREND ANALYSIS: The process of evaluating successive samples of the same data to forecast end of useful life and/or incipient failure as an aid to maintenance operations and to mission or vehicle configuration decisions.

II. Abbreviations and Acronyms

Note: Measurement nomenclature is defined in the measurement section.

A/B	Airbreather or airbreathing
APS	Auxiliary Propulsion System
APU	Auxiliary Power Unit
BITE	Built-In Test Equipment
CC	Combustion Chamber
CCC	Central Computer Complex
CCU	Channel Control Unit
C_f	Thrust Coefficient
C*	Characteristic Exhaust Velocity
DIU	Digital Interface Unit
DRM	Design Reference Model
ΔV	Change in Velocity
EPL	Emergency Power Level
FMEA	Failure Modes and Effects Analysis
FPB	Fuel Preburner
FS_1	Fire Switch #1 (Engine Start Signal)
FS_2	Fire Switch #2 (Engine Shutdown Signal)
GHe	Gaseous Helium
GH_2	Gaseous Hydrogen
GN_2	Gaseous Nitrogen
GOX	Gaseous Oxygen
GSE	Ground Support Equipment
G & N	Guidance and Navigation
HPFTPA	High Pressure Fuel Turbopump Assembly

NOMENCLATURE (Continued)

HPOTPA	High Pressure Oxidizer Turbopump Assembly
Ign	Igniter or Ignition
KSC	Kennedy Space Center
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LOX	Liquid Oxygen
LPFTPA	Low Pressure Fuel Turbopump Assembly
LPOTPA	Low Pressure Oxidizer Turbopump Assembly
LRU	Line Replaceable Unit
MPL	Minimum Power Level
MR	Mixture Ratio
MSFC	Marshall Space Flight Center
NPL	Normal Power Level
OCMS	Onboard Checkout and Monitoring System
OMS	Orbital Maneuvering System
OPB	Oxidizer Preburner
P/L	Payload
RCS	Reaction Control System
TCA	Thrust Chamber Assembly
TPF	Terminal Phase Finalization
TPI	Terminal Phase Initiation
TVC	Thrust Vector Control
VAB	Vertical Assembly Building
WTR	Western Test Range

I. INTRODUCTION

The technical approach used in this study to develop the concept for onboard checkout and monitoring of the Space Shuttle propulsion systems is described in Volume I. The baseline mission, vehicle, propulsion systems and vehicle electronics are described in Volume II, together with the analyses conducted to establish the propulsion systems' checkout and monitoring criteria. Figure I-1 is repeated in this chapter, again illustrating the technical approach; this volume presents the analyses that were conducted to define the checkout and monitoring approach, and describes the resultant concept.

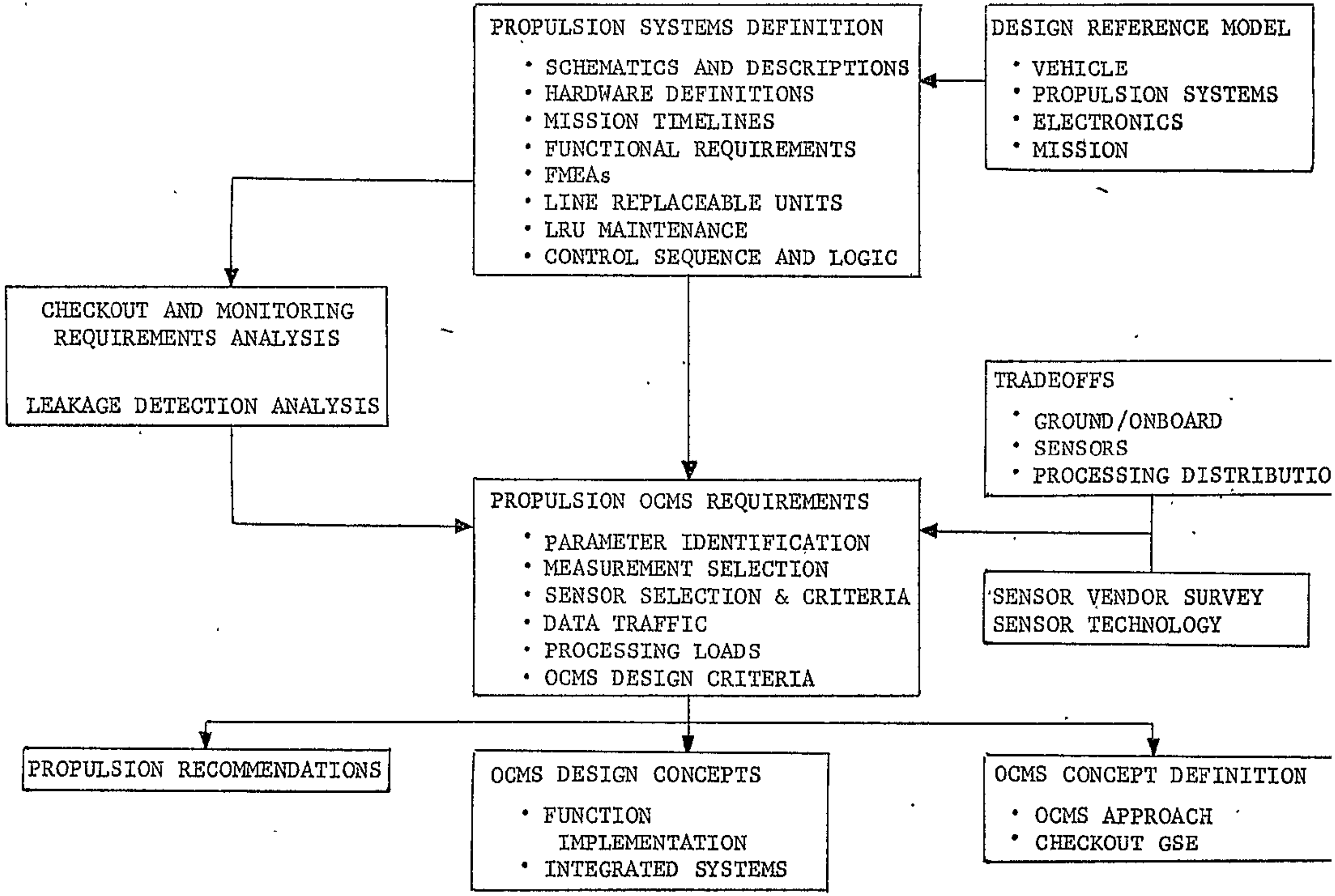


FIGURE I-1 TECHNICAL APPROACH

II. PROPULSION OCMS REQUIREMENTS

A. CHECKOUT AND MONITORING REQUIREMENTS ANALYSIS

In the early stages of this study it became apparent that to effectively develop the onboard checkout and monitoring requirements it would be necessary to devise an efficient working tool which would serve as a communication link between the propulsion personnel and the electronics personnel engaged in this effort. A method was needed to translate the propulsion subsystem definitions and functional requirements into information pertinent to the checkout function, and assemble that information in a form which would become the basis for the definition of the bulk of the checkout and monitoring requirements. Included in this task was the necessity to identify the sequences of operations of the various propulsion systems, assemblies, and elements; to identify the means of detecting failures in those operations, the means of isolating those failures to replaceable units, and the actions required as a result of such failures. In addition, it was necessary to develop the intimate relationship between checkout and control of the propulsion systems as well as identify any time or cycle sensitive elements employed by those systems.

To satisfy these requirements, a set of documentation entitled Checkout and Monitoring Requirements Analysis (C/O-MA) was developed. This was accomplished in two phases. The first phase consisted of a series of workshops by the propulsion and electronics personnel where, on a subsystem-by-subsystem basis, the mission phase functional requirements were examined. The sequences of operations were identified, time or cycle sensitive elements were identified, and a phase-by-phase mission analysis was performed to identify the checkout, monitoring, fault detection, fault isolation, failure reaction, and control requirements for each subsystem. The first natural result of this procedure was the generation of a preliminary set of subsystem measurement lists which were included at the end of each subsystem analysis. In those areas where information was either incomplete or not available, action items were noted or appropriate assumptions were made and identified. The sequence and logic diagrams which accompanied those analyses are presented in Chapter III, Volume II, of this report.

The second phase of this procedure consisted of taking the above analyses for each subsystem during a particular mission phase, and molding them into a continuous mission phase analysis. This was then re-evaluated against the subsystems requirements documentation. Finally the detailed operations of the tasks identified in the phase-by-phase analysis were added. These include the ground support equipment requirements and the detailed measurement requirements. The result is a step-by-step sequence for a nominal mission, indicating the expected values for a particular parameter at a given time, and the justification for making the required measurements. This result is contained in Appendix D of Volume IV.

B. LEAK DETECTION AND MONITORING

1. Introduction

The leakage of propellants or pressurants aboard the Space Shuttle can result in hazardous conditions from fires or explosions, reduced stage performance, or functional losses of propulsion system elements. Although the level of redundancy in the propulsion systems is such that, in general, failures of single components do not adversely affect the operational capability of the stage, the failure modes and effects analyses show that leakage is a major failure mode. As a part of the definition of the propulsion system OCMS, it was therefore necessary to define potential types of leaks and leakage sources and to identify an approach to leakage detection and monitoring which would accomplish the requisite functions of preflight checkout, readiness assessment and performance monitoring, hazard warning, etc.

The major conclusions and recommendations resulting from this study are as follows:

a. The functions of the leakage detection and monitoring system are two fold: first, the existence of external or internal leaks in the propulsion components in exceedance of component or subsystem design specifications must be detected, because such conditions can result in subnormal system performance, indicate that a redundant element no longer exists, or directly induce a hazardous condition. Secondly, the presence of hydrogen-air or hydrogen-oxygen mixtures at concentration levels and pressures in the combustible regime must be detected for hazard warning. A hybrid approach to accomplish these onboard functions is recommended. The approach consists of utilizing ultrasonic detectors for leakage detection, and a mass spectrometer/sampling probe system for concentration monitoring. The latter would also be used as the cabin gas analyzer.

b. A technology program to characterize the performance of the ultrasonic detectors with cryogenic hardware should be implemented.

c. Since the lower pressure limit for combustion of hydrogen with air or oxygen is approximately 0.15 psia, it should be a design goal to provide rapid venting of compartments to below this value during the boost phase.

d. Changes should be made to the Design Reference Model so that corrective action (such as purging, venting or abort) may be undertaken if a hazardous concentration or major leak is detected during ascent.

2. Ground Rules

a. The study encompasses detection and monitoring of leakage in the airborne vehicle systems. Launch facility items, such as propellant transfer equipment, are not included.

b. In general, large leakage resulting from a structural failure is excluded from the analysis.

c. The orbiter stage is used as the basis for the analysis because of its longer flight duration. The study results for the orbiter stage can also be applied to the booster stage.

d. The compartments are purged with an inert gas while hydrogen is being loaded and up to launch.

e. During main engine operation, any leakage from these engines into the base region downstream of the base heat shield can constitute a special hazard problem. This problem is beyond the range of this study due to the interaction of recirculating gases from the external flow field and the complex nature of the total problem.

3. Leakage Sources and Consequences

To properly understand and classify the overall leakage problem it is necessary to define potential sources and consequences of leakage.

a. Sources - The leakage sources were evaluated for each of the three propulsion systems for the orbiter, as discussed in the following. The main engine is presented in Paragraph 4.

1) Main Propulsion System

The orbiter main propulsion system is shown in Figure II-1. The components, assemblies and subsystems that are potential leak sources are as follows:

Propellant tankage
Propellant lines
Isolation/prevalve
Vent and relief valves
Fill and drain valves
Pressure regulators
Shutoff valves
Check valves
Disconnects
Sealed joints
Main engine

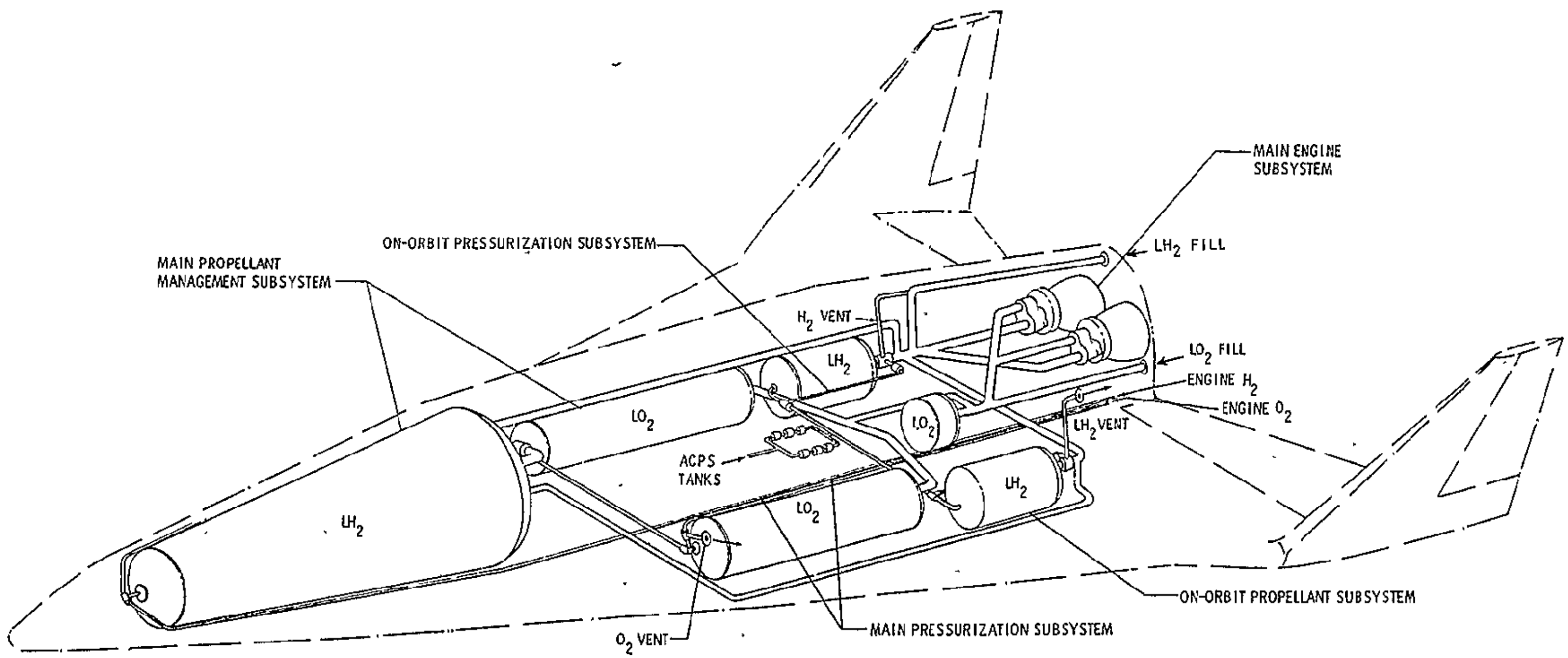


Figure II-1 ORBITER MAIN PROPULSION SYSTEM

The propellant tankage includes both the main and on-orbit tankage. These tanks will be designed and tested for structural integrity at pressures greater than the normal operating pressure. Also, there will be design specifications which will determine the maximum allowable gas leakage from the tankage. Nevertheless, it is possible for leakage to occur at penetration points for lines and at seals for manhole covers. Repeated stage usage could also cause leakage at tank welds. In the horizontal or vertical position the leakage of any liquids would rapidly vaporize to the gaseous state. If the stage were in a horizontal attitude, leakage from the large main LH_2 tank would have a tendency to accumulate at the top of the stage in whatever compartment the leak occurred. If the stage were in a vertical attitude, leakage from large main LH_2 tank would have a tendency to rise toward the front of the stage.

The propellant and pressurant lines include both vacuum jacketed lines and regular single wall tubing. The single wall tubing and ducting can leak externally. The vacuum jacketed lines can leak and lose their vacuum. All of the larger lines contain flange joints. Leakage of the seals at these joints are another leakage source.

The propellant shutoff or isolation valves could leak both internally with leakage of liquid or gas into the position indicating switch, actuator, or closed position latch and externally at the flange joints. Leakage through the gate lip seal would allow propellant into the main engine.

The vent and relief valves can leak either internally or externally. The actuation solenoid valve and the step vent solenoid valve which are both part of this valve can also leak.

The fill and drain valves which are butterfly type valves can suffer leakage mainly through the valve seat lipseal. A relief valve which is located in the center of the butterfly is also a potential leak source.

The pressure regulators can leak both internally and externally. Leakage from the atmospheric sensing port and the regulator body is defined as external leakage. Internal leakage is that which occurs through the regulator outlet or from the integral relief valve.

The check valves can incur internal leakage after repeated usage.

The fill and drain disconnects consist of an airborne half which is essentially a mating ring with sealing surfaces and a ground half with a built in butterfly valve.

2) Auxiliary Propulsion System

The orbiter stage APS is shown in Figure II-2. Those components, assemblies, and subsystems within this system that are potential leak sources are as follows:

Propellant accumulators
Propellant lines
Gas generators
Solenoid valves
Turbopumps
Turbocompressors
Heat exchangers
Check valves
APS engines

The propellant accumulators store the gaseous hydrogen and oxygen at 1500 psia. As with the main tankage, these high pressure bottles will be tested for structural integrity under pressures greater than the normal operating pressure.

The high pressure lines that connect the forward and rear accumulators are all brazed fittings which will be leak tested extensively during assembly and acceptance testing. In general they can be expected to have leak rates lower than 1×10^{-8} std cm^3/sec.

The bipropellant gas generators within the APS propellant conditioning subsystem could be a leak source for the GH_2 and GO_2 both internally and externally. Also they generate hot gases which could leak externally.

The heat exchangers which furnish the heat source to convert the LO_2 and LH_2 to GO_2 and GH_2 are devices with no moving parts. However, they are hard to inspect and do provide a potential leak path through the heat exchanger coils for hot fuel-rich combustion gases to contact liquid oxygen. This is a type of internal leakage with a potential for catastrophic failure.

The solenoid valves and check valves that control the flow of fuel and oxidizer into propellant conditioning subsystems and into the accumulator regulators can leak both internally and externally.

The APS rotating machinery which entails both turbine driven pumps and turbine driven compressors does require special consideration due to the dynamic sealing necessary to prevent leakage from such components. The principal dynamic seal types used in turbopumps and compressors are the labyrinth, face-riding, and shaft-

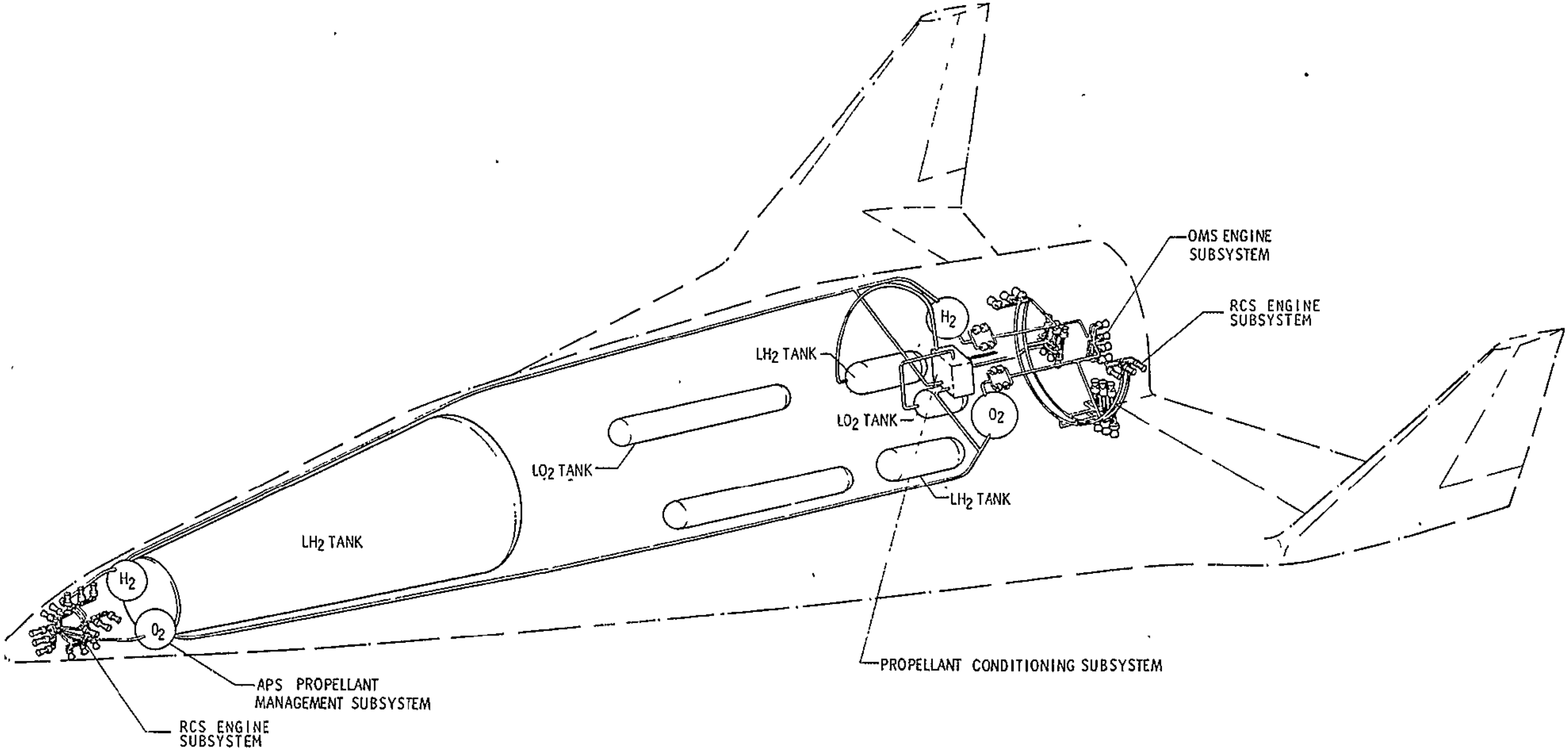


Figure II-2 ORBITER AUXILIARY PROPULSION SYSTEM

riding seals. Since all of these dynamic seals can leak at a high rate, vent lines must be connected to the cavities between two or more dynamic seals which are installed in series. This is particularly important to assure positive sealing for critical applications such as propellant seals where fuel may be on one side and oxidizer on the other side of the seals. This vent line will be connected to GSE for ground testing and will be vented through the external skin in flight.

3) Air Breathing System

The orbiter stage A/B system is shown in Figure II-3. Those components, assemblies, and subsystems within this system that are potential leak sources are as follows:

Propellant lines
Solenoid and check valves
Gas generators
Turbopumps
Turbofan engines

Since leakage in all of these types of components has been discussed in the two previous sections they will not be repeated herein except for the engine.

In the engine power assembly both the low and high pressure compressors contain special air seals to limit interstage air recirculation and high leakage would decrease performance of the turbofan engines. This would be detected by trend data analysis of engine performance. In the high and low pressure turbines there are turbine blade tip seals and interstage labyrinth seals that could leak. Again this would result in a performance loss that can be detected.

In the fuel control assembly the variable displacement vane pump will utilize dynamic seals.

The scavenge pump which removes oil from the gearbox compartment for return to the oil tank would be the most likely source of an oil leak. The loss of oil may impair the lubrication of the engine bearings and result in bearing loss and subsequent engine shutdown. In the case of prolonged storage of a turbofan engine in space on the orbiter, three problems are of concern in the lubrication assembly: vaporization of the oil to the hard vacuum, cold welding of the contact surfaces, and freezing of the oil. Turbofan engine lubrication systems are usually vented to ambient through a breather valve.

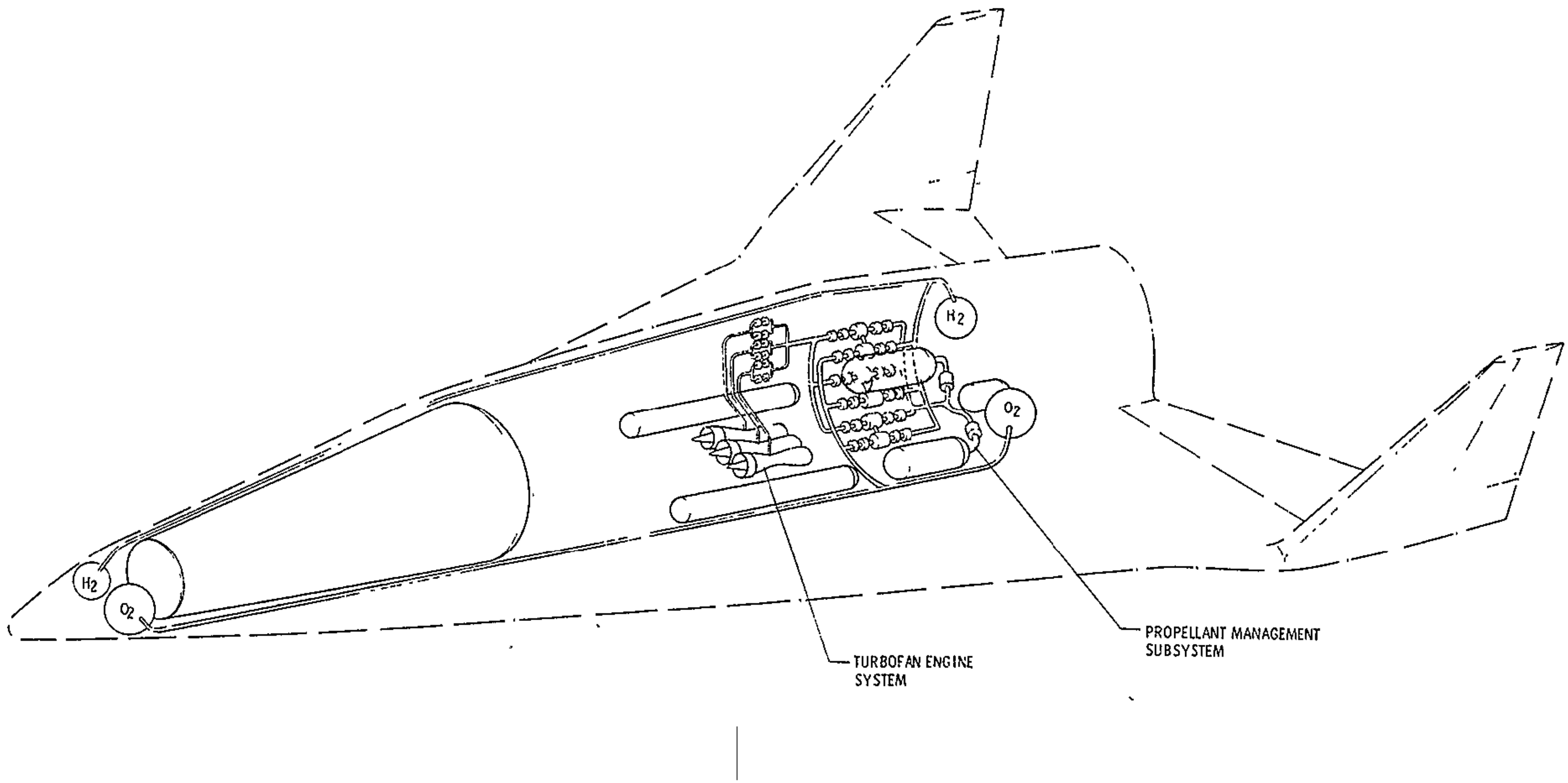


Figure II-3 ORBITER AIRBREATHING PROPULSION SYSTEM

The bearing compartments and gearboxes have carbon face seals between the stationary housing and the rotating shaft for compartment sealing. While in orbit, the leakage through these seals would drop the system internal pressure to the vapor pressure of the oil. The oil residue from the vaporized oil would contaminate most of the lubrication system. This vaporization problem can be eliminated by maintaining a minimum internal lubrication system pressure which would be monitored by the OCMS.

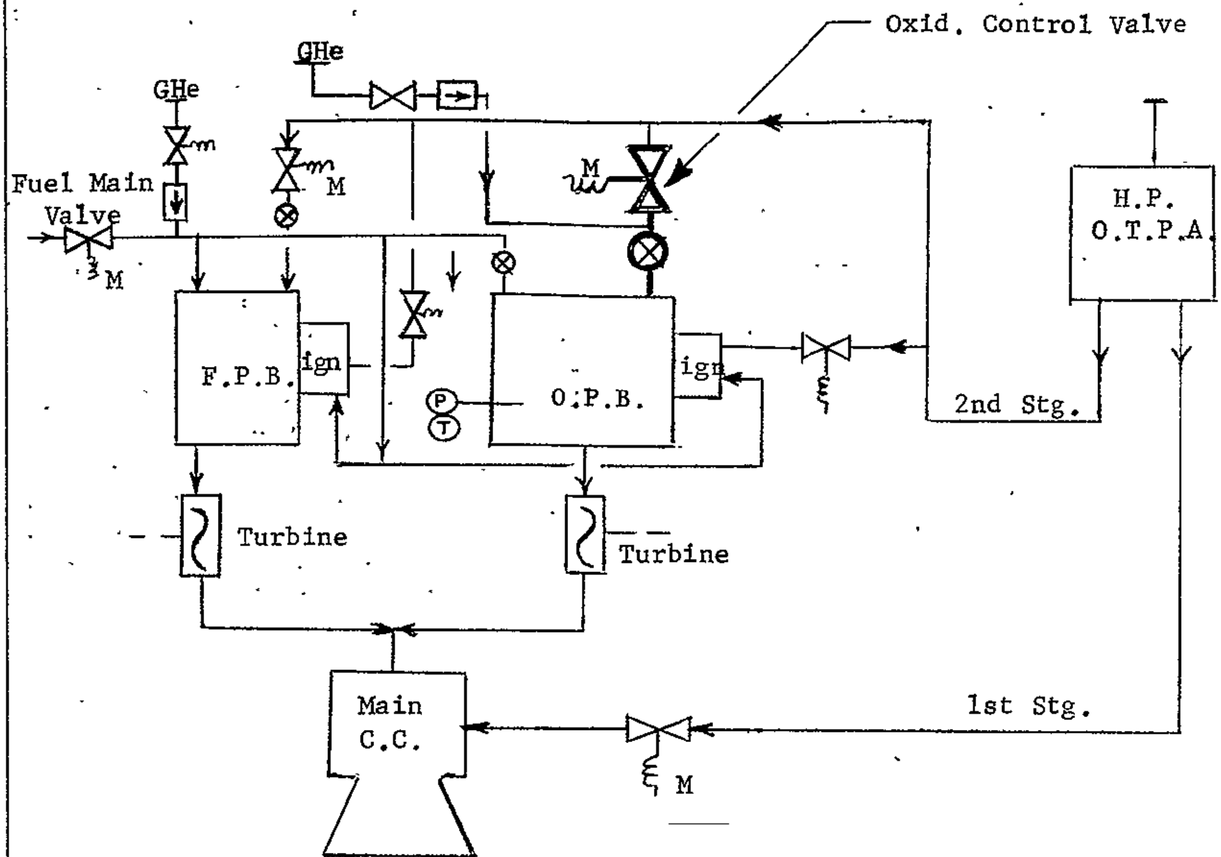
4) Main Engine and APS Engine Subsystems

In support of this study the Aerojet Liquid Rocket Company conducted a detailed leakage analysis to the component level on the Main and APS engines. Each engine component that could leak was analyzed to determine the consequences of the leak and how it could be detected. This first phase of the ALRC study resulted in an analysis sheet for each component. These analysis sheets are not presented in this report because of their bulk; an example is presented in Figure II-4. These studv results for the Main and APS engines are summarized in Figure II-5. Each component that represented a leak source is identified and the type of leak, egress point for the leak, and effect of the leak is described. The detection test method is identified.

LEAK DETECTION ANALYSIS Sheet 19 of 39

OXIDIZER CONTROL VALVE, OX. PREBURNER (1.1.1.11)

FUNCTION: Provides on-off and modulating control of oxidizer to the oxidizer preburner.



CONSEQUENCES OF LEAKAGE:

1) At Start: "Small Leak" - GHE purge dilutes oxid; "Large Leak" - High press./temp. start with possible preburner and/or turbine damage.

2) Post FS-2: "Small Leak" - Minor increase in shutdown M.R.; "Large Leak": High pressure/temp. shutdown, possible turbine damage, extended shutdown (minor).

METHODS FOR DETECTION:

1) Preburner temperature/pressure at start and shutdown. Shutdown data will be more indicative, as a leak in the igniter oxidizer valve will cause a pressure peak at start.

2) It may be possible to use an external contact-type ultrasonic leak detector in conjunction with a 25-50 psig GHE or GN_2 pressurization in maint. shop. if flight data indicates an abnormality. The design of this valve may preclude incorporation of a leakage detector probe (i.e., thermocouple), so the ultrasonic technique should be pursued. Presence of igniter oxid. valve could make location of leak a difficult task.

Figure II-4 Example of Engine Component Leak Detection Analysis

FIGURE II-5
LEAKAGE DETECTION ANALYSIS SUMMARY
MAIN ENGINE

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
1.1.1.2 - Lift-Off Seal, HPFTPA and 1.1.1.4 - Lift-Off Seal, OTPA	Fuel Leak. Face Seal, in Turbine Section of Pump. Exits Nozzle	A. None B. Fire Hazard C. Orbiter Only - Fire Hazard during Boost.	*None	*None	*Helium leak test but requires sensing at fuel main valve (parallel path), to differentiate. External ultrasonic contact probe at valve, and at pump.
1.1.1.2 - Ck. Valves for HPOTPA Turbine Bearing Coolant	Fuel Leak. Feed Line: Seat leaks in forward dir. Ret Line: Seat leaks in reverse dir. Both Exit Nozzle.	A. None B. Fire Hazard C. Orbiter Only - Fire Hazard during Boost.	Bearing Temperature.	None	Leak test with external ultrasonic contact probe
1.1.1.8 - Fuel Main Valve	Fuel Leak. Poppet Seal. Exits Nozzle	A. None B. Fire Hazard C. Orbiter Only - Fire Hazard during Boost.	Temp. Sensor downstream of Valve. Check temp. at Prop. loading, on-pad, and post-FS_2.	None	A helium leak test in shop can be performed with two types of sensors: 1) External ultrasonic probe at valve. 2) Mass. spec. probe inserted in main C.C. Igniter Tube, with a collar seal.
1.1.1.9 - Oxid. Main Valve	Oxid. Leak. Poppet Seal. Exits Nozzle	A. None B. Hard start, TCA damage. If large enough possible hazard on launch pad. C. Shutdown - high M.R. - Possible injector damage.	Temp. Sensor downstream of Valve. Check temp. at Prop. loading, on-pad, and post FS_2.	None	A GN_2 leak test with an external ultrasonic contact probe. The multiple paths for Oxid. leakage which exit the nozzle render a "sniff" test in the chamber useless.
1.1.1.11 - Oxid. Control Valve, O.P.B.	Oxid. Leak. Shutoff seal. Exits Nozzle	A. None B. Hard start. Possible preburner/turbine damage. Possible high M.R. at shutdown, with turbine damage. C. Orbiter - Hard start. Possible preburner/turbine damage. Possible high M.R. at shutdown with turbine damage.	1. Preburner pressure/temp. data at start and shutdown. Large leak would show up on pad on chamber temp. 2. Review valve design to determine whether or not a thermocouple could be incorporated in passage downstream of valve. The preferred method, however, is #1 above as it makes use of transducers already on engine for other purposes.	None	GN_2 leak test with external ultrasonic probe. Proximity of igniter oxidizer valves leaves some doubt about the specificity of this test.

*FURTHER STUDY REQUIRED.

FIGURE II-5 (Continued)

LEAKAGE DETECTION ANALYSIS SUMMARY

MAIN ENGINE

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
1.1.1.12 - Oxid. Control Valve, F.P.B.	Oxid. Leak. Shutoff Seal. Exits Nozzle	A. None B. Hard start. Possible preburner/turbine damage. Possible high M.R. at shut-down, with turbine damage. C. Orbiter - Hard start. Possible preburner/turbine damage. Possible high M.R. at shutdown with turbine damage.	1. Preburner pressure/temp. data Large leak would show up on pad on chamber temp. 2. Review valve design to determine whether or not a thermocouple could be incorporated in passage down-stream of valve. The preferred method, however, is #1 above as it makes use of transducers already on engine for other purposes.	None	GN_2 leak test with external ultrasonic probe. Proximity of igniter oxidizer valve leaves some doubt about the specificity of this test.
1.1.3.1-1 Ign. Oxid. Valve, O.P.B.	Oxid. Leak Poppet seal. Exits nozzle	A. None B. A large leak could result in igniter/preburner/turbine damage at start. C. Orbiter - A large leak could result in igniter/preburner/turbine damage at start.	1. Preburner chamber press/temp. 2. Review igniter design to deter-mine if a thermocouple could be incorporated downstream of valve. Preferred method is #1 above as it would make use of existing transducers.	None	GN_2 leak check, with external ultrasonic probe. Possible confusion with leakage in oxid. control valve exists. On-board device probably the best technique.
1.1.3.1-2 Ign. Oxid. Valve, F.P.B.	Oxid. Leak Poppet Seal. Exits nozzle	A. None B. A large leak could result in igniter/preburner/turbine damage at start. C. Orbiter - A large leak could result in igniter/preburner/turbine damage at start.	1. Preburner chamber press/temp. 2. Review igniter design to deter-mine if a thermocouple could be incorporated downstream of valve. Preferred method is #1 above as it would make use of existing transducers.	None	GN_2 leak check, with external ultrasonic probe. Possible confusion with leakage in oxid. control valve exists. On-board device probably the best technique.
1.1.3.1-3 Ign. Oxid. Valve, Main TCA	Oxid. Leak Poppet Seal. Exits nozzle	A. None B. A large leak could result in igniter/main C.C. damage pre-mature shutdown. C. Orbiter - A large leak could result in igniter/main C.C. damage premature shutdown.	1. Main Comb. Ch. Press. 2. Igniter design should be reviewed to determine if a thermocouple probe could be incorporated down-stream of valve.	None	GN_2 or GHe leak check, with probe inserted in igniter tube. This test can be successful, as the igniter chamber would be accessible. If external ultrasonic probes are proven, it could be used as there is no valve in the immediate vicinity as on the preburners.

FIGURE II-5 (Continued)
LEAKAGE DETECTION ANALYSIS SUMMARY

MAIN ENGINE

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
1.1.6.1 - LH_2 Tank Press. Check Valve	Fuel Leak. Check valve seat. Exits Nozzle. This valve is redundant to vehicle check valve.	(Leakage Statement assumes Level 1 Redundancy is already leaking) A. None B. Loss of pre-pressurization gas on pad. C. Booster: No hazard unless a premature engine shutdown occurs, then it would exit the nozzle of dead engine with possible fire hazard up to some altitude. Orbiter: Loss of pre-pressurization gas.	Pressure sensor between the two check valves. Record data at pre-pressurization and post FS_2. The sensor also provides pressurization system information.	Observe pressure sensor via engine or vehicle data system with tank pressurized.	Tank pressurization with all other valves shut off; helium mass spec. test at main TCA (not considered a practical approach, but is feasible). By installation of several shutoff valves and pressurization ports, complete shop checkout is possible, but is not recommended.
1.1.6.2 - LOX Tank Press. Check Valve	Oxid. Leak. Check valve seat, exits nozzle. This valve is redundant to vehicle check valve.	(Leakage Statement assumes Level 1 is already leaking) A. None B. Loss of pre-pressurization gas on pad. C. Loss of tank pressurant gas IF premature shutdown occurs. Probably no hazard.	Pressure sensor between the two valves would give pressurization system data as well as data on check valves.	Observe pressure sensor via engine or vehicle data system with tank pressurized.	Tank pressurization with all other valves shut off; helium mass spec. test at main TCA (not considered a practical approach, but is feasible). By installation of several shutoff valves and pressurization ports, complete shop checkout is possible, but is not recommended.
1.1.7.1-1.a Preburners Oxid. Purge Solenoid Valve	GN_2 or GHe. Exits nozzle.	Loss of oxid. backflow shut-off redundancy excessive use of GHE. If check valve AND this valve leak, possible over-pressure of GHe or GN_2 system occurs; damage to line(s), tank; premature shutdown of entire propulsion if common purge system used for all engines.	Pressure sensor at juncture of 1.1.7.1-1.a, -2.a, -2.b.	Pressure sensor in conjunction with purge system gas.	None. (See 1.1.6.1 also)

FIGURE II-5 (Continued)

EAKAGE DETECTION ANALYSIS SUMMARY

MAIN ENGINE

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
1. 1. 7. 1-1. b Main TCA Fuel Purge Solenoid Valve	GHe. Exits nozzle.	Loss of fuel backflow shut-off redundancy excessive use of GHe. If check valve AND this valve leak, possible over-pressure of GHe or GN_2 system occurs; damage to line(s), tank; premature shutdown of entire propulsion if common purge system used for all engines.	Pressure sensor at juncture of 1. 1. 7. 1-1. b and 2. c (check valve).	If cracking pressure of check valve is high enough, use of the pressure sensor in conjunction with the purge system gas could detect leakage.	None. (See 1. 1. 6. 1 also)
1. 1. 7. 1-1. c Main TCA Oxid. Purge Solenoid Valve	GHe/GN_2 Exits nozzle.	Loss of oxid. backflow shut-off redundancy excessive use of GHe. If check valve AND this valve leak, possible over-pressure of GHe or GN_2 system occurs; damage to line(s), tank; premature shutdown of entire propulsion if common purge system used for all engines.	Pressure sensor at juncture of solenoid valve and check valve (1. 1. 7. 1-2. d	If cracking pressure of check valve is high enough, use of the pressure sensor in conjunction with the purge system gas could detect leakage.	None. (See 1. 1. 6. 1 also)
1. 1. 7. 1-1. d HPOTPA Seal Cavity Purge Solenoid Valve	GHe Exits overboard lines from HPOTPA.	Excessive use of GHe is possible.	None	Helium sniff test with purge system pressurized.	None
1. 1. 7. 1-1. e Engine System Purge Solenoid Valve	GHe/GN_2. Exits nozzle.	A. None B. Possible excessive use of purge gas. C. None	None	None	Periodic check with gas decay test and/or external ultrasonic probe.
1. 1. 7. 1-2. a Oxid. Preburner Oxid. Inlet Purge Check Valve	GHe/GN_2 Exits nozzle.	See 1. 1. 7. 1-1. a Also may result in minor mixture ratio control problem.	See 1. 1. 7. 1-1. a	See 1. 1. 7. 1-1. a	See 1. 1. 7. 1-1. a
1. 1. 7. 1-2. b Fuel Preburner Oxid. Inlet Purge Check Valve	GHe/GN_2 Exits nozzle.	See 1. 1. 7. 1-1. a Also may result in minor mixture ratio control	See 1. 1. 7. 1-1. a	See 1. 1. 7. 1-1. a	See 1. 1. 7. 1-1. a

FIGURE II-5 (Continued)
LEAKAGE DETECTION ANALYSIS SUMMARY

MAIN ENGINE

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
1.1.7.1-2.c Main TCA Fuel Inlet Purge Check Valve	GHe. Exits nozzle.	Same as 1.1.7.1-1.b	Same as 1.1.7.1-1.b	Same as 1.1.7.1-1.b	Same as 1.1.7.1-1.b
1.1.7.1-2.d Main TCA Oxid. Inlet Purge Check Valve	GHe. Exits nozzle	Loss of oxid. backflow shut-off redundancy. Excessive use of GHe. If solenoid valve and this valve leak, possible over-pressure of GHe or GN_2 system occurs; damage to line(s), tank may occur, with premature shut-down of entire propulsion system if common purge system used for all engines.	Pressure sensor at juncture of check valve and solenoid valve. 1.1.7.1-1.c	Same as 1.1.7.1-1.c	Same as 1.1.7.1-1.c
1.1.7.1-2.f Fuel Suction Line Purge Check Valve	No leak if GHe system pressure is up.	None	Function in forward direction is most significant. Can be accomplished with existing suction pressure meas.	----	----
1.1.7.1-2.g Oxid. Suction Line Purge Check Valve	No leak if GHe system pressure is up.	None	Function in forward direction is most significant. Can be accomplished with existing suction pressure meas.	----	----
1.1.8.1 Extendible Nozzle Coolant Valve (Orbiter Only)	Fuel. Exits nozzle.	A. None B. Fire Hazard. C. Fire Hazard up to some altitude.	1. Temp. probe downstream of valve.	None	Helium leak test using external ultrasonic probe (contact).

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FIGURE II-5 (Continued)
LEAKAGE DETECTION ANALYSIS SUMMARY

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

MAIN ENGINE

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
All Unshrouded joints (no carry-off ducts). These will by definition be 10^{-4} scc/sec or better, normally	Fuel. Joint seals to engine comp. area.	A. None B. Fire hazard. C. Fire hazard up to some altitude.	On-board GH_2 sensors in engine area. Then shop tests to localize source.	-----	Leak test with portable ultrasonic detector to locate leaks. Then helium mass spectrometer for leakage rate.
	Oxidizer. Joint seals to engine comp. area.	A. None B, C. None (Neglecting gross leakage due to seal failure).	None. If engine compartment is enclosed, an O_2 concentration analyzer is recommended.	-----	Periodic checks with an ultrasonic probe with system pressurized with GN_2 is recommended. (Microphone type probe)
All shrouded joints with carry-off ducts and inerting gas.	Fuel. Joint seals, to point of over-board dump.	A. None B. Fire hazard if above inerting capability. C. Fire hazard up to some altitude.	GH_2 sensor on duct near point of egress. If excessive concentration appears, shop test would be required to isolate joint.	-----	Helium press. test with external ultrasonic probe to localize leakage source.
	Oxidizer. Joint seals, to point of over-board dump.	A. None B., C. None (Neglecting gross leakage due to seal failure)	None	-----	Periodic checks with ultrasonic probe with system pressurized with GN2.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

FIGURE II-5 (Continued)

LEAKAGE DETECTION ANALYSIS SUMMARY

ACPS

MISSION PHASE CODE:

A. FERRY
B. GROUND
C. FLIGHT

LEAKAGE SOURCE	TYPE OF LEAK AND EGRESS POINT	EFFECT OF LEAK	DETECTION TEST METHODS: ON-BOARD DETECTION IN CONJ. WITH FUNCTIONAL OUTPUTS	DETECTION TEST METHODS: SHOP OR OTHER TEST IN CONJ. WITH ON-BOARD EQUIP.	DETECTION TEST METHODS: SHOP OR OTHER TEST WITH NO ON-BOARD EQUIP.
2.1.4 - Bi-Propellant Control Valve	Fuel. Seat Seal Leak. Exits Nozzle.	A. None B. Fire Hazard C. Fire Hazard to some Altitude.	1. GH_2 sensor in RCS compartment. 2. Ultrasonic contact probe on each thruster	Helium (or other gas) pressurization in conjunction with ultrasonic contact probe.	Helium leak test, with helium mass spectrometer.
	Oxid. Seat Seal Leak. Exits Nozzle.	A. None B. None, unless gross leak occurs, and fuel leak also occurs. C. None - Some possibility of a "hard start"	1. Ultrasonic contact probe on each thruster.	Helium (or other gas) pressurization in conjunction with ultrasonic contact probe.	Helium leak test, with helium mass spectrometer.
2.1.2 - Igniter Valves	Fuel. Seat Seal Leaks. Exits Nozzle.	A. None B. Possible Fire Hazard. C. Possible fire hazard up to some altitude.	Same as 2.1.4 (Fuel)	Helium (or other gas) pressurization in conjunction with ultrasonic contact probe.	Helium leak test, with helium mass spectrometer.
	Oxid. Seat Seal Leaks. Exits Nozzle.	A. None B. None C. None Above excludes gross failure.	Same as 2.1.4 (Oxid)	Helium (or other gas) pressurization in conjunction with ultrasonic contact probe.	Helium leak test, with helium mass spectrometer.
2.1.3 - Isolation Valve	Fuel, Oxid. No Egress, unless one of above valves leaks	A., B., C. - None without failure (leakage) of 2.1.2 or 2.1.4.	1. Pressure transducers in each circuit at juncture of this valve and 2.1.4, observe with pressure upstream. 2. Test in conjunction with 2.1.2, 2.1.4 (recommended approach)	Helium (or other gas) pressurization in conjunction with ultrasonic contact probe. Open control valve to permit flow.	Helium leak test, with helium mass spectrometer. Open control valve to permit flow.

4. Consequences of Leakage

The first consideration in specifying the total allowable leakage of a system is that the system must not leak sufficient commodities to cause system failure during its mission duration. The orbiter stage has a mission duration considerably greater than that of the booster stage, and is, therefore, the limiting case.

The total allowable orbiter component leak rates will be governed for each propulsion system by the following requirements:

Main Propulsion System - Maintain internal tank pressure and propellants in the on-orbit tanks during the orbital mission phase.

APS - Maintain a sufficient supply of propellants in the accumulators to meet the RCS thruster demands during reentry operation, and to meet the APU requirements.

A/B System - Maintain a sufficient flow rate of fuel to allow proper operation of the turbofan engines for the approach and landing phase of the mission.

The second consideration in specifying the allowable leakage is that of the functional loss of a component, assembly or subsystem from leakage either directly or indirectly. The direct effect of leakage from a component that effects it alone can be seen in the FMEA's that were presented in the first quarterly progress report. In general, due to the level of redundancy in the propulsion systems, failure of a single component will not have a major impact on the stage. However, from a close examination of the failure mode and effects analysis performed to the parts level on the critical components, leakage (aside from failure due to normal wear) is the major cause of a component failure.

The third consideration in specifying the allowable leakage is the hazard presented to both ground personnel and the flight crew resulting from H_2/O_2 or H_2/air mixtures.

The internal orbiter structural arrangement will consist of conventional skin/stringer/frame aircraft construction as shown in Figure II-6. The propulsion tankage and equipment will be enclosed in bulkhead sections which in turn result in a series of compartments.

Ground support equipment would be used to purge all compartments with dry nitrogen prior to launch and with dry helium just before (30 min.) loading propellants. During flight all of these compartments would be vented to ambient conditions. A mixture of gaseous hydrogen and gaseous oxygen will combust if both constituents are present in a concentration level above 4%, an ignition source of 5 millijoules or greater is present, and the pressure is above 0.15 psia.

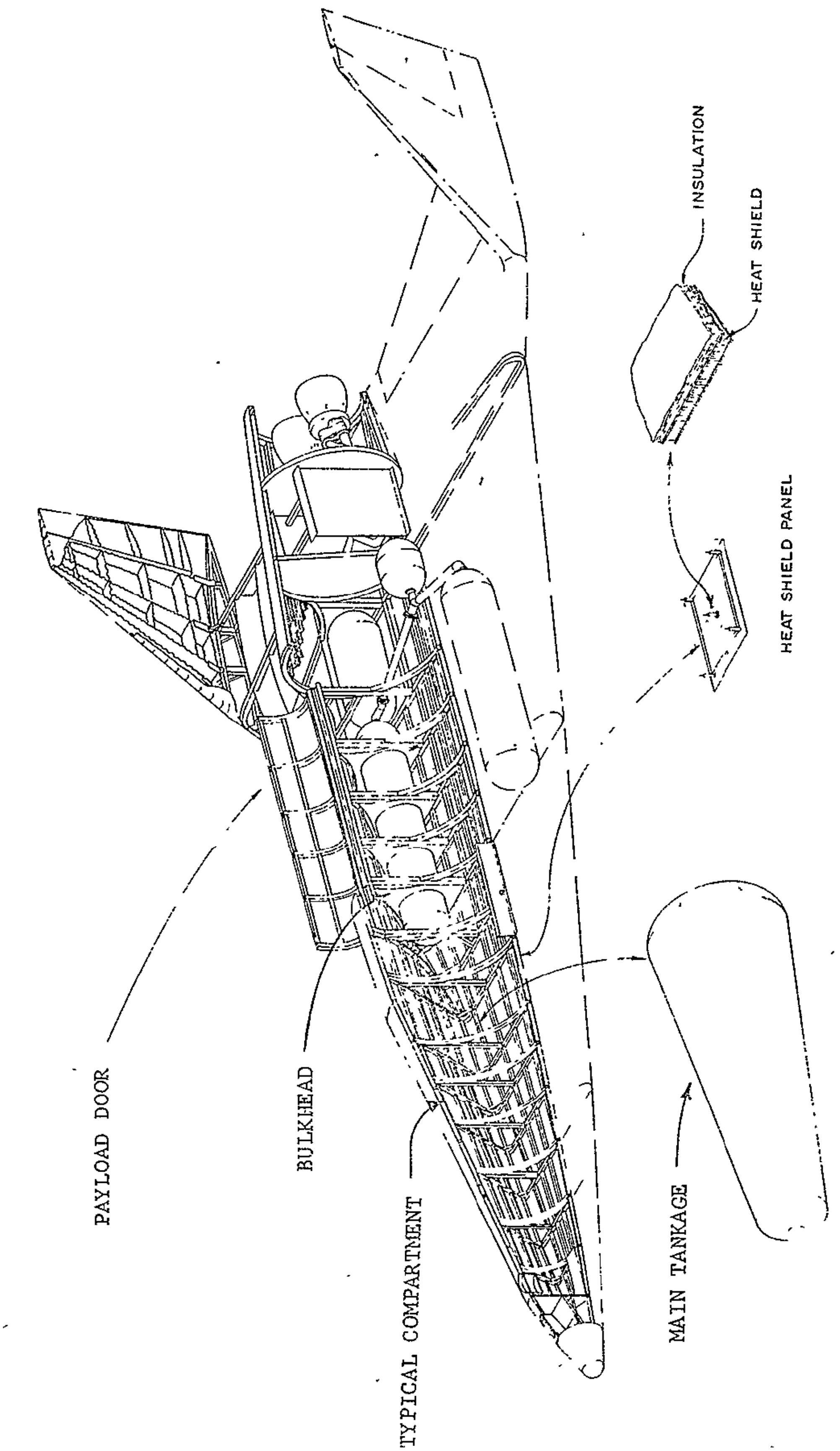


FIGURE II-6 ORBITER STRUCTURAL DETAILS

5. Mission Phase Critical Leakage Testing

The leak testing and associated safety operations necessary for the orbiter propulsion systems has been divided into four major phases. These phases are as follows:

Factory acceptance leak testing
Pre-flight testing and purge operations
In-flight monitoring
Post-flight safing

The rationale for this division is due to the OCMS requirements, GSE requirements, and allocation of time to conduct certain tests and operations. The factory acceptance testing is included to allow a baseline total allowable leakage estimate and to identify those tests necessary to insure low leakage for safe pad operations.

The onboard systems, flight hardware and ground hardware necessary to accomplish all of the above mentioned tests and operations is identified in this section, and the details on such hardware are discussed in Section 7.

a. Factory Acceptance Leak Testing - These leak checks are comprehensive survey and build-up type of testing to detect leaks in all potential problem areas. Design deficiencies, manufacturing problems and equipment malfunctions will be detected and corrected at this time. Components will first be tested, then built up into assemblies after which assembly leak checks will be performed. Finally, subsystems and systems as installed will be leak checked. This phase of leak testing will employ the airborne leak detection system (as it becomes available during system buildup) for those tests for which it can provide sufficient sensitivity. Normal ground test methods will also be employed.

b. Pre-Flight Leak Testing - The Pre-flight leak testing of the orbiter stage is that testing which takes place after either factory acceptance leak testing for a new stage or after maintenance for a stage returning from a flight. These tests would take place during the Prelaunch and Launch Mission Phases.

The system integrity (leakage) checks are performed on each propulsion system in a separate operation. All purge systems are off at this time. The hydrogen side of the main propulsion system boost LH_2 tankage will be pressurized with dry Helium at a pressure of 40 psia. All of the compartments forward of the full bulkhead (designated in Figure II-6) will be monitored by the on-board mass spectrometer and ultrasonic detectors through the OCMS. The on-orbit LH_2 tankage will then be leak checked in a like manner. The oxygen side of the main propulsion system boost LOX tankage will be pressurized with dry helium at a pressure of 25 psia. Those compartments behind the full bulkhead will now be monitored bv the

on-board systems. During these sequential tests and before the valves at the tank outlets are activated, all instrumentation downstream of these compartments are monitored for any pressure build-ups. Following this series of tests the valving is operated to allow helium to flow into the propellant lines, and the ultrasonic leak detectors are monitored. Next, valves are opened to permit accumulators pressurization. The compartment located in fromt of the LH_2 tank and the aft compartment are monitored during this test phase. All OCMS systems are left in an active state to monitor leakage until the next major cycle.

Prior to hazardous servicing operations at T-17 hours the system compartment purge GSE is connected to the vehicle and purging with dry N_2 is begun. Loading of the APS-GH_2 and GO_2 is the next operation to be performed. During such loading the compartments containing these tanks are monitored for the presence of leakage of GH_2 or GO_2 at 1500 psia.

During LH_2 and LO_2 pre-chill, slow-fill, fast-fill, topping and replenishment operations, the vehicle will be in a vertical position. All compartments are being purged and the on-board mass spectrometers are monitored on a continuous basis. Since the crew is not yet on-board the orbiter, the on-board display will be monitored by TV camera.

The helium purge system must be operating prior to the LH_2 tanking for thirty minutes. If tanking has begun, and the He purge system fails, the compartments would probably contain 99.9% He. O_2 would begin entering the interstage through the exhaust ports and leakage areas from the outside atmosphere. Also, leakage from the propulsion system components would begin to build up within the volume.

c. <u>In-Flight Monitoring, Detection, and Safing</u> - The in-flight leak monitoring system must provide for detection from fire-switch #1 to GSE connection for post-flight tankage purging. The on-board systems must be operational during the boost phase when the compartment pressures will be rapidly changing and the docked phase which can last up to seven days in duration.

As the mated stages leave the ground, mixing through the leakage areas is increased due to the movement of the shuttle. As the atmospheric pressure decreases with altitude, the compartment pressures will correspondingly decrease. Normal leakage from the propulsion system components would be expected to vary only slightly upon increasing altitude. Constant H_2 leakage into a compartment with decreasing pressure would cause an increasing percentage of H_2.

The ambient pressure drops below 0.15 psia (the combustion limit for hydrogen/oxygen mixtures) before separation of the booster and orbiter stages and at approximately 120 seconds from liftoff. The compartment pressures will reach this same pressures level at some increment after

this time based on the venting rate out of the compartment into the ambient. The most critical inflight time period from a leakage standpoint are these 2 + Δt minutes from shuttle liftoff, since this is the time period inflight in which leakage could result in a compartment fire or explosion.

d. Post-Flight Safing - Post-flight leak testing is accomplished by ground crews who will first unload any propellants in the tankage and purge all the systems with dry helium. The compartment purge GSE will also be connected for a series of compartment purges with dry GN_2.

7. Flight System Hardware Approach

a. Mass Spectrometers - Two mass spectrometers are used redundantly and are both located in the crew compartment. Each utilizes a sampling line which extends the full length of the stage, with branch lines running off this main sampling line for compartment sampling (Figure II-7).

The spectrometer operates by sampling a gas through a small orifice, the size of which is determined by the ambient pressure surrounding the equipment. When the equipment is to be used over a wide range of ambient pressures, the orifice size must be varied to be small for high pressures and large for low pressures. To utilize both spectrometers redundantly, a set of valves will be activated to switch the orifice size for atmosphere or in-space operation.

At the end of each branch line is a solenoid valve which is controlled by an electronic scanning or timing device which opens one valve at a time. A vacuum pump will be necessary to evacuate the main sampling line and to bring compartment samples past the sampling port of the mass spectrometer. This is necessary for the atmospheric operation; for vacuum operation, the sampling line will be evacuated to space by utilizing valving.

The mass spectrometers would be an instrument such as the Perkin-Elmer unit utilized on the Metabolic Activity Experiment for the Skylab Program, and would occupy approximately 500 cubic inches and which weighs 26 lbs. per instrument. The Perkin-Elmer unit is qualified for a Saturn 1-B launch environment and operating life of 30 days (720 hours). It utilizes 28 Volts - D.C. and provides a 0-5 Volt output. It contains a six detector unit which would be set-up for CO_2, O_2, N_2, H_2, H_2O, and He. This instrument would have to be calibrated after each flight with a calibration sample taken from a gas bottle.

The one limitation anticipated with the mass spectrometer system is the time required to cycle through from the aft compartment into the instrument. Based on an assumed velocity in a sampling line of 40 feet per second, it would require 4 seconds for a gas sample to be introduced into the mass spectrometer from the aft compartment. If the response, clean-up, pump, valve signals and valve actuation times are added to this sampling time, then the total time between compartment readings could be in the range of 10 seconds.

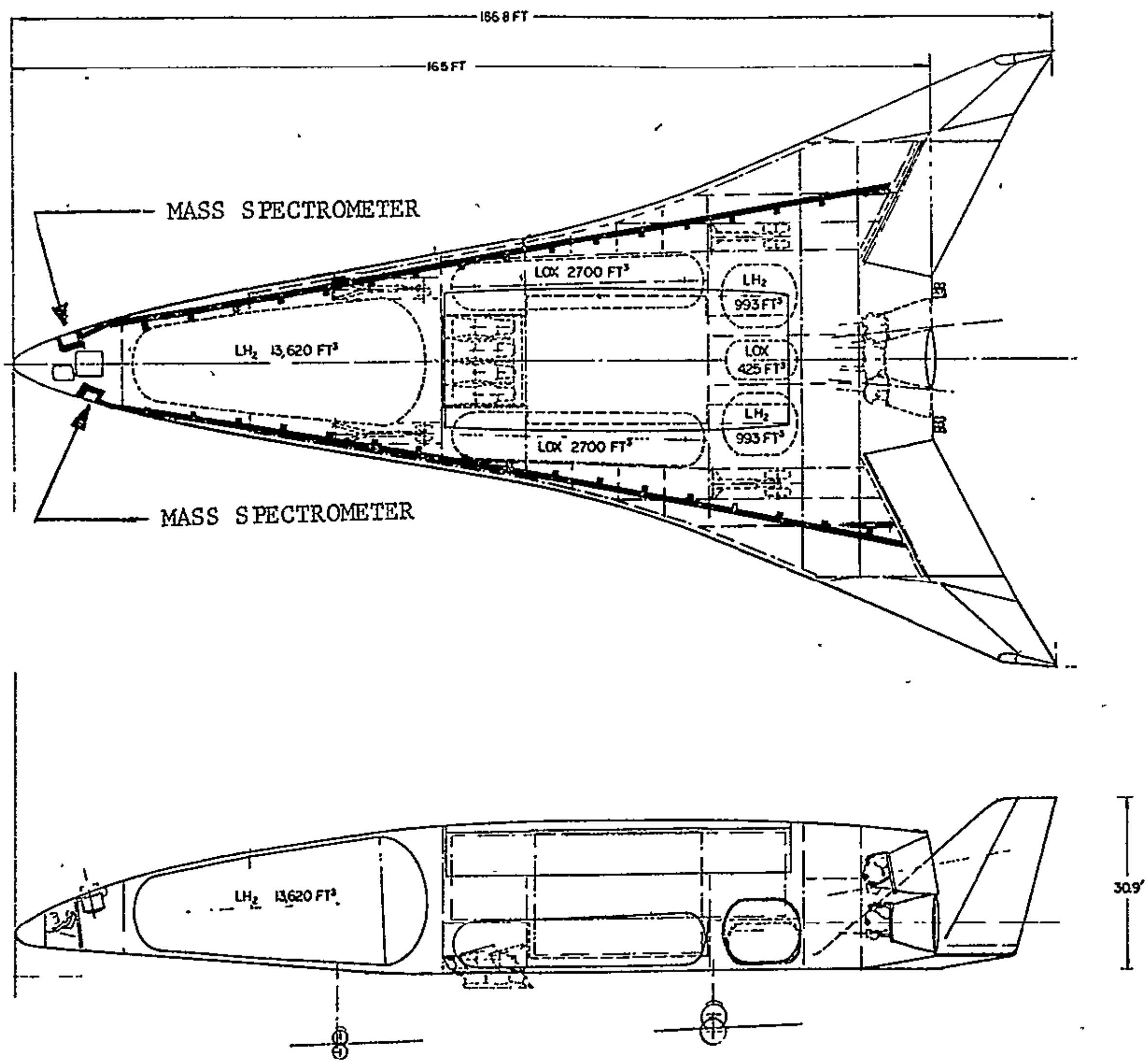


Figure II-7 Mass Spectrometer/Sampling System

b. Ultrasonic System - The on-board ultrasonic leak detection system would consist of contact sensors mounted directly to the propellant ducting and pressurant tubing, probably together with directional microphones of the scanning type to provide a broad coverage of those components located in each compartment.

Leakage in pressurized systems may be detected by means of the sound energy generated in a fluid vortices which can accompany leakage. The frequency of the leakage noise ranges from the audible to the ultrasonic. The ultrasonic component of the leakage noise is broadly peaked at a frequency of 30 to 50 Kilohertz. A sensitivity of approximately 10^{-3} std cm^3/sec. is anticipated, with the sensors bonded directly to the component to be monitored for leakage, or directly to the ducting near the component.

Based on an assumed location of a sensor for every 5 to 10 feet of ducting, the following number would be required:

- Main propulsion - 44 sensors
- APS - 64 sensors
- Air breathing propulsion - 18 sensors

All of the transducers for the same diameter line or same size component could probably be alike; however, different types or calibrations may be necessary for unlike components. Also, it would be important to determine the characteristic noise signal for each component without leakage under nominal operating conditions. The interference noise can also be generated by a component upstream or downstream of that component under observation and therefore, this noise must be properly identified to distinguish such interference from actual leakage.

The output of these 126 sensors will be monitored by a selector switch controlled and monitored by the on-board computer.

Prior to implementation of the onboard ultrasonic leak detection system, a technology program would be required to characterize the performance of the system with cryogenic hardware with high background acoustic levels.

This page not used.

III. MEASUREMENTS AND SENSORS

III. MEASUREMENTS AND SENSORS

A. Measurement Requirements and Analysis

Preliminary measurement requirements were derived from the Checkout and Monitoring Requirements Analysis of each subsystem and from the FMEA's of each LRU and related components. Short-form preliminary measurement lists were then prepared in draft form.

To obtain visibility of measurements with respect to their purpose, adequacy for fault detection and isolation, possible unnecessary redundancy, and desirable additional redundancy, a matrix analysis technique was developed. The working document for this analysis was titled "Measurement Selection Matrix", its primary purpose being the selection of measurements to optimize the checkout and monitoring function. Figure III-1 presents one such matrix.

The matrix shows all pertinent measurement indications within a subsystem that might be expected in event of a single failure occurring in that subsystem. It also shows other usages of the measurements that were identified in the Checkout and Monitoring Requirements Analysis or in the LRU Maintenance Procedures. Failure criticality was included to serve as an additional piece of information in determining the need for a measurement. Fault indications were placed in the matrix cells by analysis of the subsystem schematic, tracing out the measurement responses to each potential failure mode.

The first step in using the matrix is a column-by-column examination to determine if a positive indication of each failure exists. In the example of Figure III-1, failure of either of the LH_2 check valves to close gives no positive indication of the failure. However, by a procedure described in the Checkout and Monitoring Requirements Analysis for this subsystem, Pump Discharge Pressure is used to detect this failure mode. This is noted by the checkmark under Procedural Fault Isolation in the matrix (cross referenced to this failure mode by the symbol ▲).

The next examination of the matrix is again on a column-by-column basis to determine if unique sets of indications are present such that any failure can be isolated to a particular LRU by logical deduction. Note that although low speed of the turbine gives the same indications as low speed of the pump, this set of indications is still unique to the LRU (the turbo-pump assembly). If the same set of indications were present for a failure mode of another LRU, either a special procedure or additional measurements would have to be added to enable isolation

This page not used.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED

FIGURE III-1 MEASUREMENT SELECTION MATRIX

Booster Hydrogen Conditioning Subsystem	LRU No.	9				10													11								12					Other Usage of Measurement					
	LRU Name	LH_2 Chk Val				Turbopump													Turbopump Suct. Valve								G.G./HT. Exch										
	Component	A		B		Turbine				Pwr. Train				Pump					A				B				GG		H.E.								
Measurement	Failure Mode	Fails to Open	Fails to Close	Fails to Open	Fails to Close	Unbalance	Overheat	Low Speed	No Rotation	Friction	Lube Leak	Lube Pump Loss	No Rotation	Unbalance	Friction	Exter. Leak	Low Speed	Not Rotation	Fails to Open	Fails to Close	Intern. Leak	No Excitation	Fails to Open	Fails to Close	Intern. Leak	No Excitation	Exter. Leak	Blckd Passage	Blckd Passage	Minor Coil Leak	Major Coil Leak	Control	Op. Time	Maint. Proc.	Proc. Fault Isol.	Trend Data	Ground Op.
Press. Gas Gen. Chmbr.		H		H					H																		L	L			H	✓					
Press., Turbine Lube												L																				✓					
Press., Pump Disch.		H	▲	H	▲			L	O				O			L	L	O									O	L			H	✓			✓▲		
Temp., Gas Gen. Chmbr							H																				L	L			L	✓				✓	
Temp. Turbine Lube										H																						✓				✓	
Level, Turbine Lube											L																					✓					
Speed, Turbine		L		L				L	O				H				L															✓	✓				
Posit'n, LH_2 Isol. Valve		Ø	C	Ø	C														C	Ø	C	C	Ø	C	C	Ø						✓		✓			✓
Posit'n, LH_2 Pump Suct. Valve		Ø	C	Ø	C														Ø	C	C	Ø	C	Ø	C	C						✓		✓			✓
Exit'n, LH_2 Isol. Valve		+	x	+	x														+	x	x	x	+	x	x	+								✓			
Exit'n, LH_2 Pump Suct. Valve		+	x	+	x														+	x	x	+	+	x	x	x								✓			
Press., Heat Exch. Outlet																													L	L	L						
Speed, Pump		L		L				L	O				O				L	O									O	L			H						
Press., Pump suction																			O	H	O	O	O	H	O	O											
Vibr., Turbine						H																														✓	
Vibr., Pump														H																							
Temp., Pump Bearing															H																					✓	
Failure Criticality →	Ferry	3	4	3	4	*	*	3	3	*	*	*	3	*	*	3	3	3	3	4	4	3	3	4	4	3	1	2A	3	3	3	*Indicates Incipient Failure					
	Ground	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	3	3	3	3	3						
	Flight	3	4	3	4	*	*	3	3	*	*	*	3	*	*	3	3	3	3	4	4	3	3	4	4	3	1	2A	3	3	3						

Measurement Indication Legend:

H = High
L = Low
0 = Zero

Ø = Open
C = Closed

\+ = Voltage Present
x = Voltage Absent

The next step is using the matrix is a line-by-line examination to determine if any measurements can be removed without affecting the uniqueness of the sets of indications for fault isolation. In the example, four measurements fall in this category. These are Gas Generator Chamber Pressure, Turbine Speed, Pump Speed, and Pump Suction Pressure. These are then considered candidates for deletion from the measurement list. Of these, Gas Generator Chamber Pressure and Turbine Speed are noted as required for control and Turbine Speed is additionally noted as required for compiling operating time records on the Turbopump Assembly. This leaves Pump Speed and Pump Suction Pressure as redundant measurements, subject to deletion from the measurement list if no other reasons for their retention can be discovered and defined. Also, the need for both Turbine Speed and Gas Generator Chamber Pressure for control should be questioned to determine if both are truly necessary.

If Pump Speed is deleted as a measurement requirement, only Pump Discharge Pressure is left to indicate the no-rotation failure mode of the pump. If this were a higher criticality failure mode than the "3" noted, it would be desirable to retain Pump Speed as a backup measurement. In the case of the two higher category failure modes included in this example (Gas Generator External Leakage and Gas Generator Blocked Passage) adequately redundant indications (3) are available even when Pump Speed is deleted.

In summary, the matrix analysis technique is a recommended approach for finalizing measurement selections. It was used in this study for the less-complex subsystems; however, because the approach was totally manual the matrix methods full benefit could not be realized through application at a system level. If programmed for computer usage as a design aid, it will represent a powerful tool for measurement requirements analyses.

As measurement requirements were analyzed, they were tabulated in a suitable format. This format was designed to be used in conjunction with the OCMS Checkout and Monitoring Requirements Analysis (Volume IV, Appendix D) and the sensor criteria and requirements (Tables A-3 and A-4 of Appendix A). Together, these define the measurements and their usage to the extent that all necessary data is compiled for determining the following:

1. Availability of suitable sensors

2. Sensor development and technology requirements

3. OCMS hardware functional requirements and distribution

4. Data Bus traffic

The measurement requirements tabulations are presented in Table A-1 of Appendix A. A discussion of the column headings and codes used in the measurement requirements tabulation is included in the same appendix, as is a tabulation of measurement identity codes (Table A-2). Measurement locations for the booster are shown on the schematics of Figures III-2 through III-5. In cases where subsystems or subsystem sections are redundant, only a typical case has been presented. This has been done to enhance the clarity of the schematics by keeping the congestion to a minimum.

Table III-1 presents a summary of the measurement requirements by measurement types. The total numbers of measurements for the booster and orbiter propulsion systems are 3,130 and 1,348 respectively. Results of efforts to reduce the quantity of measurements indicate that the current criteria on degree of redundancy verification, fault detection and isolation, trend detection, and performance monitoring prohibit any further significant reduction. Therefore, it is concluded that the present estimates of measurement quantities are reasonable for the assumed baseline configuration. A relaxation in any of the above criteria would, however, allow a significant reduction in the number of measurements. It should be emphasized that when the final shuttle propulsion systems are designed, where checkout and monitoring will be prime factors for the designer's consideration at all levels of design, a significant reduction in the required quantity of measurements is likely to result.

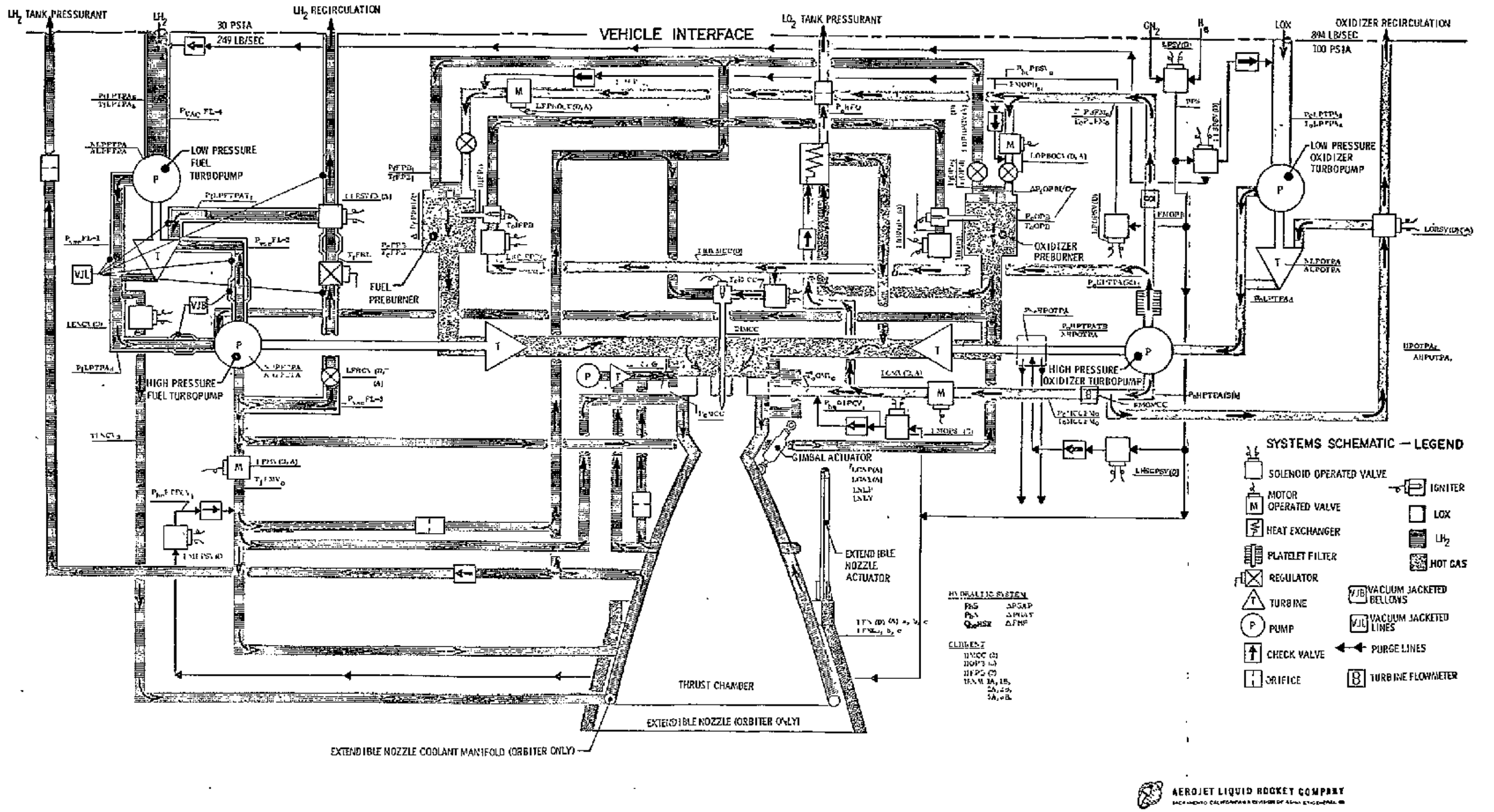


FIGURE III - 2 MAIN ENGINE MEASUREMENTS

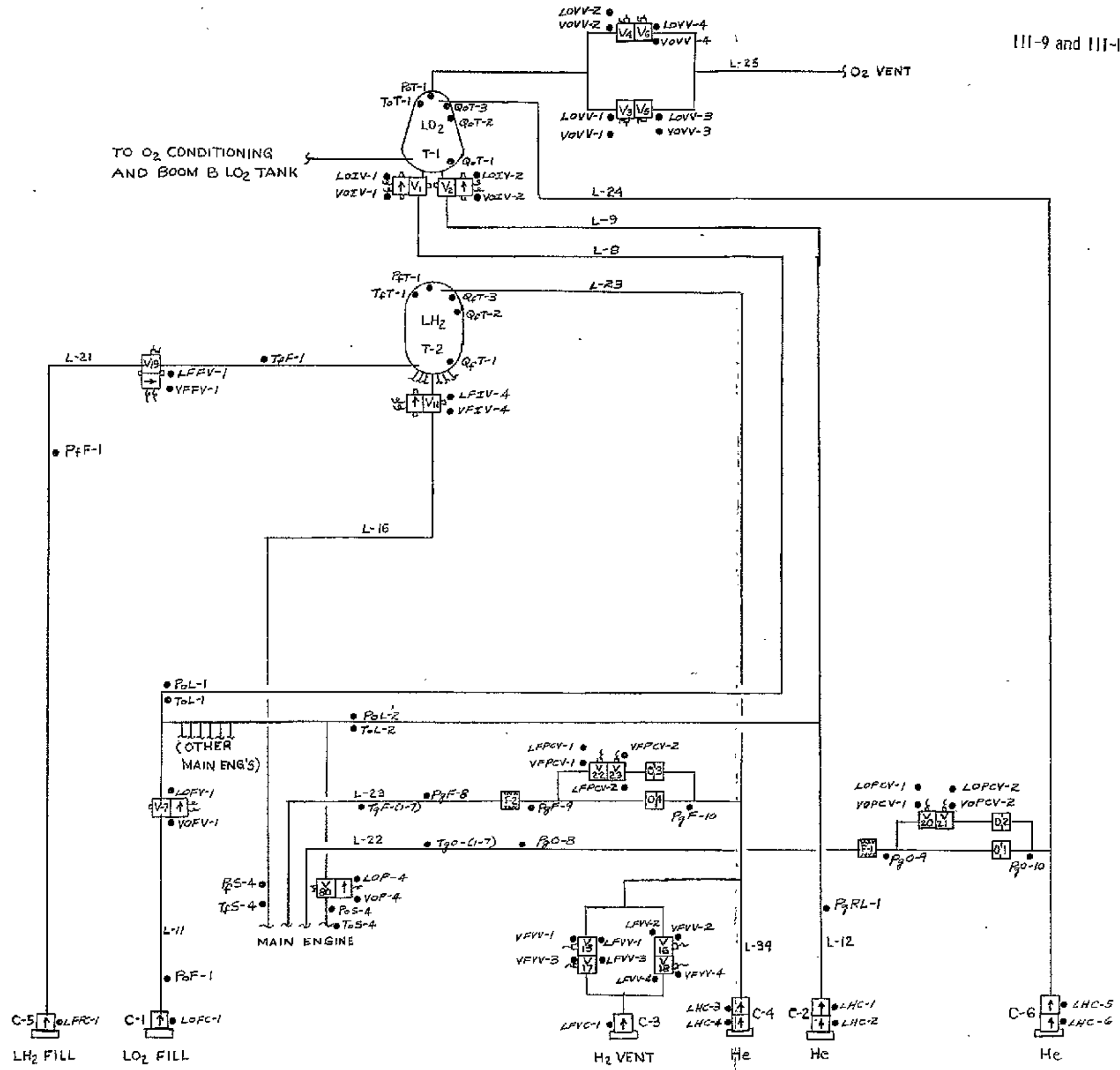


FIGURE III -3 BOOSTER MAIN PROPULSION MEASUREMENTS

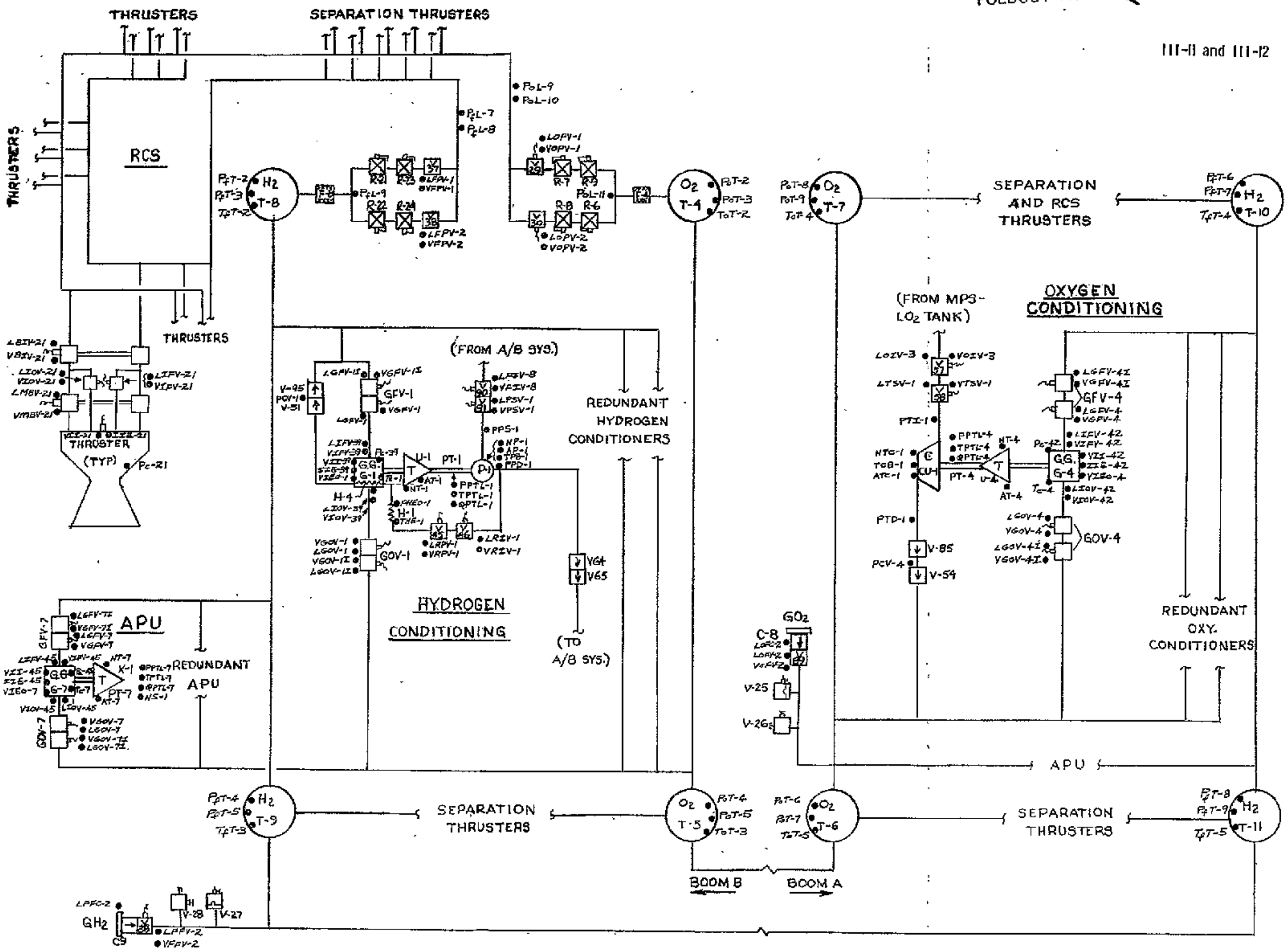


FIGURE III-4 BOOSTER AUXILIARY PROPULSION MEASUREMENTS

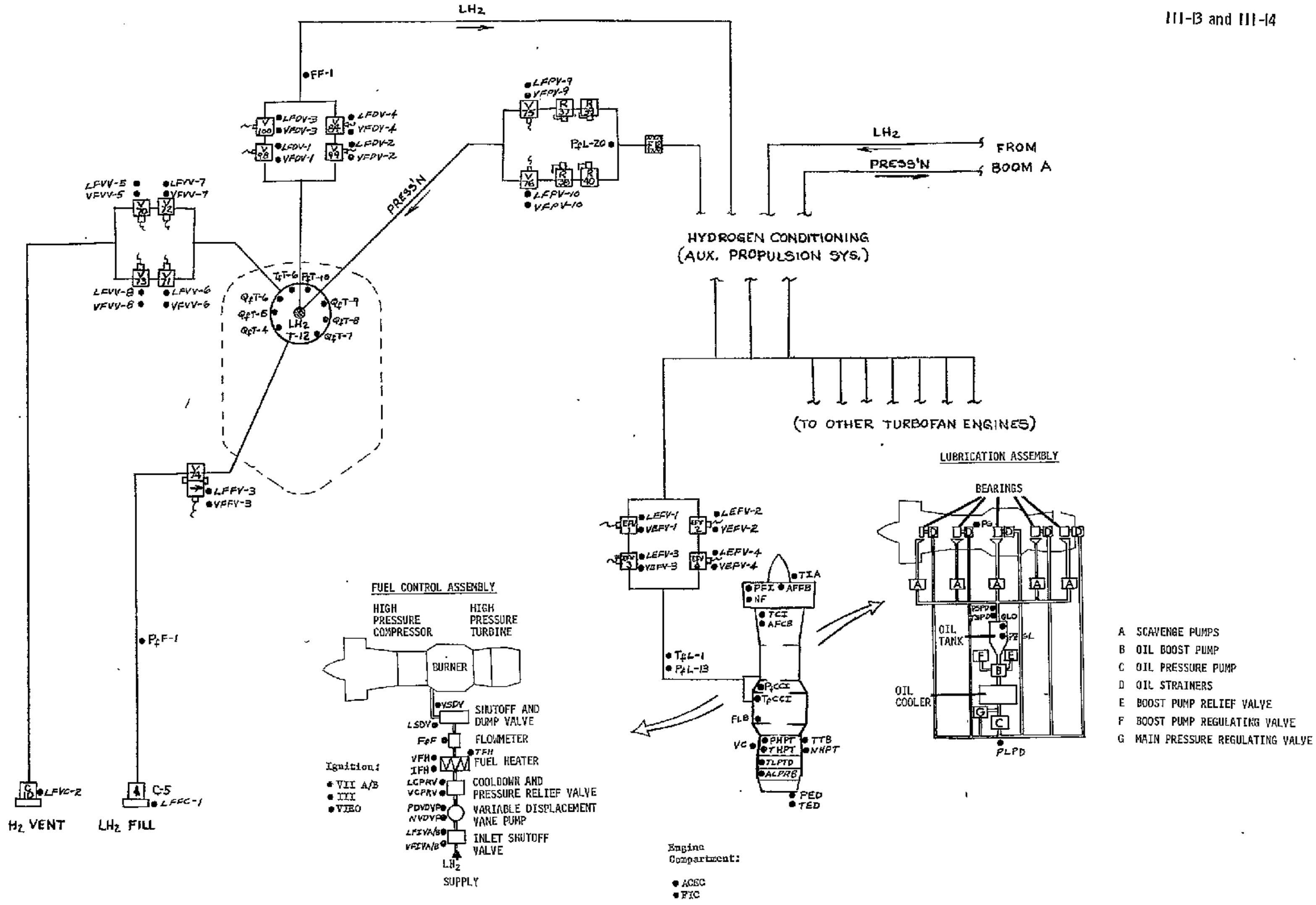


FIGURE III-5 BOOSTER AIR BREATHING PROPULSION MEASUREMENTS

TABLE III-1

MEASUREMENT SUMMARY*

	BOOSTER					ORBITER				
	MAIN ENG	A/B ENG	LEAK DET'N	ALL OTHER	TOTAL	MAIN ENG	A/B ENG	LEAK DET'N	ALL OTHER	TOTAL
PRESSURE	434	63		182	679	62	27		121	210
TEMPERATURE	168	63	32	110	373	24	27	6	53	110
DISCR. POSIT'N	266	21	64	374	725	52	9	12	263	336
ANALOG. POSIT'N	140				140	22				22
QUAN. GAGING	14	7		33	54	2	3		24	29
FLOW RATE	56	7		2	65	8	3			11
FLAME DET'N	42	14			56	6	6			12
VIBRATION	56	28	252	15	351	8	12	126	18	164
CURRENT	42	14		47	103	6	6		43	55
SPEED	56	21		18	95	8	9		15	32
VOLTAGE		49		408	457		21		298	319
GAS ANAL.			32		32.			48		48
TOTALS	1,274	287	380	1,189	3,130	198	123	192	835	1,348

* Does not include redundancy

B. Sensor Identification

In order to match suitable sensing techniques to the identified measurement requirements, a sensor investigation was conducted. This investigation consisted of a vendor survey; a literature search and review of selected papers, articles, and reports; attendance at oral presentations by NASA contractors engaged in related study programs; telephone and personal contacts with vendors and study contractors; and in-house coordination with Martin Marietta groups engaged on Space Shuttle Phase B Study tasks. In addition, a detailed study of approaches to leakage detection and monitoring was completed (reported in chapter II of this volume), and a trade-off study was conducted to determine the merits of utilizing digital output transducers as opposed to analog output transducers. Documents reviewed included the interim and final reports of recent and current NASA-contracted studies with objectives related to sensor technology for the Space Shuttle. These studies were:

Contract NAS10-7251 - Propellants and Gases Handling in Support of Space Shuttle, Martin Marietta Corp.

Contract NAS10-7291 - Study to Develop Improved Methods to Detect Leakage in Fluid Systems, J. L. Pearce and Associates, Inc.

Contract NAS8-24526 - Gaseous Hydrogen Detection System, General Electric Corp.

Contract NAS10-7145 - Study of Techniques for Automatic Self Contained Readiness Assessment and Fault Isolation for Ground and On-board Mechanical Systems, General Electric Corp.

Contract NAS8-21488 - Evaluation and Demonstration of a Propellant Quantity Gaging System for Auxilliary Propulsion Systems, Marquardt Corp.

Findings from this investigation and the application of these findings to the propulsion OCMS measurement requirements are discussed in the following paragraphs.

1. Vendor Survey

A survey letter requesting information on advanced and current sensors, applicable to the Space Shuttle Propulsion System, was sent to the suppliers listed in Table III-2. Forty-three out of the ninety-three vendors contacted responded with information of technical value, covering the entire range of information expected with a minimum of 2 vendor responses per type of sensor. Information derived from this vendor survey was used to establish a current technology base from which identification of the sensors required to implement the parameters on the OCMS Measurement List could be initiated.

Data obtained from the vendor survey confirms that most of the baseline propulsion system measurement requirements can be satisfied by proved and widely used sensing and conditioning techniques. In general, considerable progress has been made in recent years in miniaturization, compensation techniques, and design for stability and reliability of sensors. Integrated circuit and film deposition techniques, showing up in the present generation of transducers, have allegedly resolved many of the environmental, accuracy, and calibration stability limitations previously associated with conventional sensing and conditioning techniques. For example, sensors employing the strain gage principle of transduction are now making use of thin film deposition techniques, eliminating strain gage bonding agents and thus greatly improving the long term stability and the reliability of the transducer. One such transducer, a pressure transducer manufactured by Statham Instruments, uses a thin ceramic film deposited onto the pressure diaphragm as an insulator upon which four strain gages are vacuum-deposited and connected into a bridge circuit.

Although sensing techniques for most of the measurement requirements identified in this study are available and are being used in production sensors, these sensors are likely to require modifications to provide compatible mounting configurations and/or characteristics to match the specific application. It would be mandatory to standardize on as few mounting designs and characteristics as possible, to be cost effective.

2. Digital-Output vs. Analog Output Sensors

It is generally acknowledged that in a system employing digital techniques for evaluation and transmission of data, it is desirable to convert signals to digital form as close to the

This page not used.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PRECEDING PAGE BLANK NOT FILMED

TABLE III-2 Sensor Vendor Survey

VENDOR	TYPE OF SENSOR TECHNOLOGY INFORMATION EXPECTED, X, AND/OR RECEIVED, (X)																	
	PRES.	TEMP.	FLOW	EVENT, SW.	POSITION, ATTITUDE	QUAN., LEVEL	VIB., SHOCK	ACOUS.	ROTA. SPEED	ACCEL	VELOCITY	FORCE, STRAIN	MASS	FREQ., PHASE	CURR, PWR, VOLT	I.R., U.V.	GAS LK. DETECT	REMARKS
1. Rosemount Engineering, Minneapolis	X	X	X															Air Data
2. Bell & Howell, Instr. Div. Pasadena	(X)																	Digital
3. Kistler Instr., Sundstrand Clarence, N.Y.	(X)						(X)	(X)		(X)		(X)	X					
4. Gulton Ind., C.&I. Costa Mesa, Ca.	(X)		X	(X)	X		(X)	(X)		(X)		X	X					
5. Statham Instr. L.A.	(X)						(X)			(X)		(X)						Solid State,Thin Film
6. Rosemount Engineering, Rep. St. Anne, Mo.	X	X	X															
7. Fisher & Porter Co. Warminster, Pa.			(X)															
8. Conrac Corp., Avion. Gp. El Monte, Ca.	X	X		X	X		X	X		X	X	X	X					
9. Endevco Corp. Pasadena	X						X			X		X	X					
10. Whittaker, Instr. Div. N. Hollywood, Ca.	X	X		X	X		X			X	X	X	X					
11. Honeywell, Inc., Home Off. Minneapolis	(X)	X	(X)	X		(X)				(X)			(X)			(X)		Special Meas Devices
12. Kaman Nuclear Colo. Springs	(X)	X			(X)		(X)	(X)		X								Var RF Imped.
13. Transoncis, Inc. Lexington, Mass.	X	(X)	(X)			(X)												
14. Beckman Instr. Fullerton, Ca.																	(X)	Special Meas. Devices
15. Bendix Corp. Nav. & C. Div. Teterboro, N.J.	(WILL NOT RESPOND)				X													Optical
16. Hycal Engineering Sante Fe Springs, Ca.		(X)																Specialty Temp Devices
17. Systron-Donner Corp. Concord, Ca.										X	X							
18. Conductron Corp. St. Charles, Mo		(X)														(X)	X	Flame-Out Detect. Spectral Anal.
19. Bell Aerosystems Co. Buffalo										X	X							
20. United Controls, XDCR. Div. Redmond, Wash.	(X)	(X)		(X)	(X)		(X)			(X)	(X)	(X)						Thermal Sw.
21. Borg Warner Contr. Santa Ana, Ca.	(WILL NOT RESPOND)								X	X								
22. Clevite Corp., G.&C. Div. El Monte, Ca.					X					X								
23. Bourns Inc., Instr. Div. Riverside, Ca.	X				X					X								Potentiometer
24. Humphrey, Inc. San Diego	X			(X)	X					(X)								
25. Standard Controls Seattle	(X)			X														
26. BLH Electronics Waltham, Mass.		X										X						
27. K West Westminister, Ca.	X	(X)		(X)			X	X		X								Pwr Sup, Sig Cond
28. Fairchild Controls Div., F.C.&I. Mountainview, Calif.	(X)									X								Potentiometer,Gyro
29. Electro Sonic Contr. Manteca, Ca.	X	X		(X)	(X)	X						X						Counter

TABLE III-2 Sensor Vendor Survey (Cont.)

VENDOR	TYPE OF SENSOR TECHNOLOGY INFORMATION EXPECTED, X, AND/OR RECEIVED, (X)																	REMARKS
	PRES.	TEMP.	FLOW	EVENT, SW.	POSITION, ATTITUDE	QUAN. LEVEL	VIB., SHOCK	ACOUS.	ROTA. SPEED	ACCEL.	VELOCITY	FORCE, STRAIN	MASS	FREQ., PHASE	CURR, PWR, VOLT	I.R., U.V.	GAS LK. DETECT	
30. G.E., Sales Oprn. Wilmington, Mass.	X	(X)	(X)	X	(X)	(X)			(X)				(X)		Current (X)	X		Optical, Special Devices
31. Fenwal Elec. Framingham, Mass.		(X)																
32. Conax Corp. Buffalo	(X)	(X)				X												
33. Foxboro Co. Foxboro, Mass.	X	X	(X)			X			X					(X)				
34. Hewlett-Packard Palo Alto, Ca.	X	X							X			X				X		Special Devices
35. Instr. Tech. Corp. Dallas	X				X	X	X					X						
36. Kavlico Elec. Chatsworth	(X)				(X)	X						(X)						LVDT
37. Pivan Engineering Co. Chicago	X	X				X			X			X						
38. Solid State Elec. Corp. Sepulveda, Ca.	(X)						X		(X)					(X)	(X)			
39. Avco Corp. N.Y.		X		X	X											X		Special Devices
40. Kollsman Instr. Corp. Syosset, N.Y.	X	X	X	X	X	X	X					X						
41. Precision Sensors, Inc. Trumbull, Conn.	X	X	(WILL	NOT RESPOND)		X												
42. Sun Elec., Aerosp. Div. Chicago	X	X				X			X					X	X	X		Special Devices
43. Bailey Meter Co. Wickliffe, Ohio	X	X	X															Special Indicators
44. Bendix Corp., Envir. Sci. Div. Baltimore	X		X	X	X	X						X						Special Devices
45. Biztek Co. Toluca Lake, Ca.	X	X				X	X		X									
46. Canadian Research Instit. Ontario, Can.		X																Optical, Humidity
47. Coffing Ind. Corpus Christi, Texas	X				X	X			X									
48. Dynasciences Corp., Subsid of Whittaker Chatsworth, Calif.	(X)	(X)		(X)	(X)		(X)	(X)				(X)						
49. CBS Labs Stamford, Conn.		X														X		
50. Collectron Corp. N.Y.	(WILL	NOT RES	POND)		X	X			X			X						
51. T.A. Edison Ind., Instr. Div. W. Orange, N.J.																		Special Devices
52. Reeves Instr. Div., D.C. of A. Garden City, N.Y.	(WILL	NOT RES	POND)				X											
53. Columbia Res. Labs., Inc. Woodlyn, Pa.	X	X		X	X		X		X	X	X							Lin. Var. Dist. XDCR (LVDT)
54. Gen. Prec. Sys., Inc. Aerosp. Gp., Singer Little Falls, N. J.				X	X					(X)	(X)	X				X		Optical
55. Sparton S.W., Inc. Albuquerque	(X)			(X)	(X)						(X)							Constant Current Source
56. Templine Gardena, Calif.		(X)																Specialty Temp. Devices
57. Delavan Mfg. Co. W. Des Moines, Io.						(X)												
58. Thermetrics Div., Exotic Mtls. Costa Mesa, Ca.		X																Specialty Temp. Devices

TABLE III-2 Sensor Vendor Survey (Cont.)

VENDOR	TYPE OF SENSOR TECHNOLOGY INFORMATION EXPECTED, X, AND/OR RECEIVED, ⓧ																	REMARKS
	PRES.	TEMP.	FLOW	EVENT, SW.	POSITION, ATTITUDE	QUAN., LEVEL	VIB., SHOCK	ACOUS.	ROTA. SPEED	ACCEL	VELOCITY	FORCE, STRAIN	MASS.	FREQ., PHASE	CURR, PWR, VOLT	I.R., U.V.	GAS LK, DETECT	
59. Bogue Electric Patterson, N.J.	(WILL NOT RESPOND)			X														Actuators
60. Thermal Systems Los Angeles, Calif.		ⓧ		ⓧ														Exhaust gas temp.
61. Consol. Contr. Corp., Condec Corp. Bethel, Conn.	X	X			X	X												
62. Ampex Corp, Instr. Div. Redwood City, Ca.																		Special Meas. Instr.
63. Sperry Gyroscope Div., Sp. Rand Great Neck, N.Y.					X		X											
64. Lewis Engineering Co. Nangatuck, Conn.		X		X	X													
65. Singer Co., Metrics Div. Bridgeport, Conn.		X																Special Devices
66. M.B. Elec. Div., Textron New Haven, Conn.	ⓧ																	
67. B&K Instr., Inc. Cleveland, Ohio	(WILL NOT RESPOND)						X											
68. Ametek, Inc., I&C Sellersville, Pa.	X			X	X	X			X			X						
69. Acoustica Associates L.A.			X	X	X	X												
70. Airesearch Mfg. Co., Garrett Torrance, Ca.	X	X				X												Air Data
71. A.C. Elec., Div. of G.M. Corp. Oak Creek, Wis.		X				X			X									
72. Genisco Techn. Corp. Compton, Ca.	ⓧ	ⓧ		ⓧ			ⓧ			ⓧ		X						
73. Adel Div., Delaval Turbine Burbank, Ca.	X					X												
74. Atlantic Res. Corp. Costa Mesa, Ca.	X	X										X						
75. Autronics Corp. Pasadena, Ca.									X					ⓧ	ⓧ			
76. Transducers, Inc. Sante Fe Springs, Ca.	X						X					X						Solid State
77. Eastech, Inc. Plainfield, N.J.			ⓧ															
78. Hoke, Inc. Cresskill, N.J.	(WILL NOT RESPOND)		X															
79. Clevite Corp., Brush Instr. Div. Cleveland, Ohio																	X	Gas Analysis
80. Bytrex, Inc. Waltham, Mass.	ⓧ						ⓧ			ⓧ		ⓧ						
81. RDF Corp. Hudson, N. H.		ⓧ																Specialty Temp. Devices
82. Honeywell, Inc., Ind. Div. Fort Wash., Pa.	(WILL NOT RESPOND, SEE NO. 11) X	X	X															
83. Honeywell, Inc., Microsw. Div. Freeport, Ill.	(WILL NOT RESPOND, SEE NO. 11)			X														
84. Honeywell, Inc., Test Instr. Div. Denver																		Specialty Test Instr.
85. Beckman Instr., Inc. Cedar Grove, N.J.	(WILL NOT RESPOND, SEE NO. 14)																X	Gas Anal.

TABLE III-2 Sensor Vendor Survey (Cont.)

VENDOR	PRES.	TEMP.	FLOW	EVENT, SW.	POSITION, ATTITUDE	QUAN, LEVEL	VIB., SHOCK	ACOUS.	ROTA. SPEED	ACCEL	VELOCITY	FORCE, STRAIN	MASS	FREQ., PHASE	CURR, PWR, VOLT	I.R., U.V.	GAS LK. DETECT	REMARKS
	TYPE OF SENSOR TECHNOLOGY INFORMATION EXPECTED, X, AND/OR RECEIVED, (X)																	
86. Victory Engg. Corp. Springfield, N. J.		(X)																
87. Bendix, Montrose Div. So. Montrose, Pa.	(X)	(X)		(X)	(X)				(X)									
88. Metrophysics, Inc. Santa Barbara, Calif.	(X)																	Photometric Instrum., Digital
89. Hamilton, STD (Univ. Air) Farmington, Conn.	(WILL NOT RESPOND) X	X			X	X	X					X						
90. Crescent Engineering Long Beach, Calif.					X													LVDT
91. Simmons Precision Prod. Inc. Vergennes, Vermont			(X)			(X)			(X)			Torque (X)						Torque, Motors, Activators Panel Indicators
92. Dynamatec Corp, Cocoa Beach, Florida (J.L. Pearce & Assoc., Inc.)																	(X)	KSC Study
93. Boeing, Co., Research-Kent Seattle, Washington								(X)										Acous. emission ~MHz, Detects Strain/Rigid Materials
Total Type Sources Expected	50	44	16	25	30	25	22	7	16	21	8	25	7	4	4	8	5	Total All Types 317
Total Type Sources Received	19	15	7	10	8	5	8	5	4	9	3	7	2	3	3	2	2	112

source of the signal as possible. For this reason, a digital output pressure transducer developed under contract to NASA/MSFC by Metrophysics Inc. is of particular interest. This device employs a built-in analog-to-digital converter to provide a 10-bit serial digital output word upon command, at up to 500 times per second. A common pulsed reference is provided to both a strain gage bridge and the converter to make the output insensitive to variations in excitation voltage. The concept can be adapted to any bridge network that can be pulsed.

Upon an extension to their original contract, Metrophysics intends to incorporate addressing, bus isolation, and limit comparison capability into the digital output transducer. This would provide interface compatibility with a data bus, allowing sensors to attach directly to the vehicle data bus.

A trade-off study was made, comparing three methods of using this digital output transducer against the use of analog output transducers. The three methods of using the digital output transducer are shown in Figure III-6. In Method "A", the transducers interface directly with the vehicle data bus. Method "B" interfaces the transducers to a sub or auxiliary data bus under control of a Digital Interface Unit (DIU). Method "C" interfaces the transducer directly to the DIU. In Method "C" the transducers contain no addressing capability, but are commanded to output their serial digital words by individual command lines from the DIU.

Method A has some limitations. First, the planned addressing capability for the transducer will allow only 30 transducers to be attached to the data bus. Secondly, to attach a transducer to three or more active data busses would require the addition of voting logic to the address recognition capability of the transducer. Thirdly, block data transmission, to reduce addressing traffic on the data bus, is not available. In Method "B" these limitations are resolved by the characteristics of the sub data bus. Thirty transducers attached to such a bus, controlled by a single DIU, is reasonable. More than one sub bus could be controlled by one DIU if necessary to allocate more than 30 transducers to that DIU. If these busses are required to be redundant, they can be operated such that only one bus is active at a time, eliminating the requirement for voting logic. Blocking of data for transmission on the vehicle data bus would be accomplished in the DIU by adding a sequencing capability (discussed in Chapter IV, Section A.2).

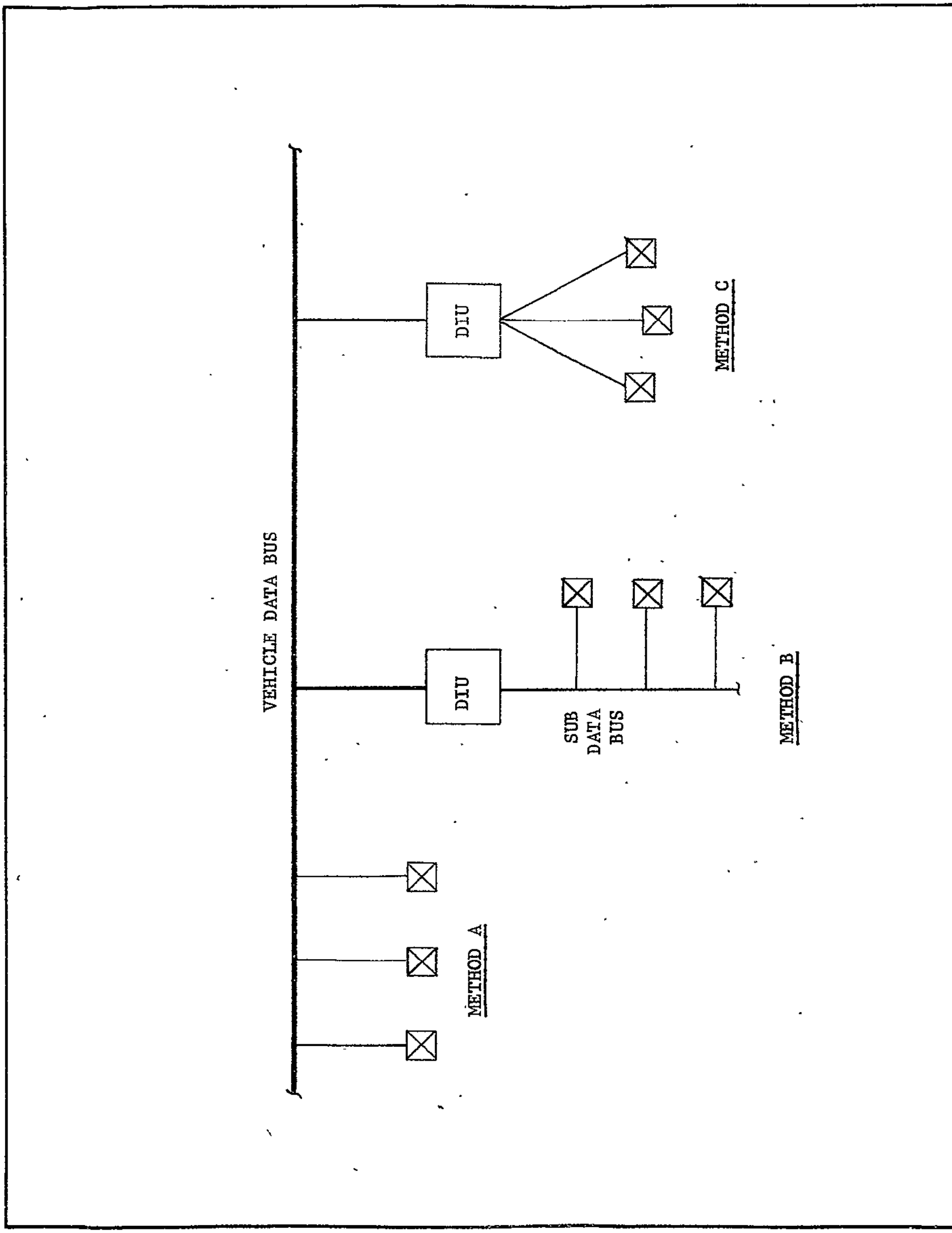


Figure III-6 Methods for Interfacing Digital-Output Transducers

Method "C" has none of the limitations of Method "A" and requires no addressing capability in the transducer. In addition, it requires no sequencing capability in the DIU for block data transmission. By proper design, either method could probably be made as reliable as the other.

Hardware procurement cost per measurement channel was used as a basis for quantitative comparison of the three methods with each other and with analog-output transducers serviced by a DIU. It was assumed that costs in addition to hardware procurement (installation, software, system integration, etc) would be the same for either method. The following estimates of hardware element procurement costs were made:

a.	Average cost of basic analog output transducer	$350
b.	Cost per transducer to provide built-in A/D conversion	850
c.	Cost per transducer to provide addressing and bus isolation	250
d.	Cost of basic DIU (packaging, bus interface, self test)	3750
e.	Cost of A/D converter in DIU	850
f.	Cost of sub data bus	1500
g.	Cost of DIU analog input switching (per transducer)	120
h.	Cost of DIU discrete output to command transducer output (per transducer)	60
i.	Cost of analog cabling to DIU (per transducer)	20

Costs per measurement channel were then computed as follows:

Method "A" cost per channel $= a + b + c = \$1450$

Method "B" cost per channel $= a + b + c + \frac{d + e}{n} = \$1450 + \frac{\$5250}{n}$

were n = number of channels

Method "C" cost per channel $= a + b + \frac{d}{n} + h = \$1260 + \frac{\$3750}{n}$

Analog-output transducer cost per channel $= a + \frac{d + e}{n} + g + i$

$$= \$490 + \frac{\$4600}{n}$$

These costs are plotted against number of channels in Figure III-7. These curves indicate that the use of analog-output transducers will provide a lower-cost system, saving on the order of $600 per measurement channel over any of the investigated digital-output transducer methods. There may, however, be individual specific cases where the digital-output transducer will be a logical choice, based on distance of the transducer from the DIU or simplification of engine controller interfaces. Where digital-output transducers are employed, Methods A, B or C could be used, depending on distribution of the measurements and redundancy requirements. It should be emphasized that a simplified approach was used in this evaluation, and that the resultant tentative conclusion could possibly be altered by introducing factors that would be available in a detailed design study.

3. Sensor Requirements

Sensor requirements are presented in two ways. The first presentation is by Sensor Criteria sheets. Table A-3 of Appendix A is a collection of these Sensor Criteria, or short-form specifications, covering all of the sensor requirements for the main engines. The sheets in this table are numbered to correspond with the Measurement Type identifications contained in the measurement list of Table A-1 of Appendix A. The second presentation of sensor requirements is by a tabular format. Table A-4 of Appendix A presents sensor requirements in this manner for the remainder of the identified measurements. Again, the sensor types are identified with a code that corresponds with the Measurement Type identifications in the measurement list.

For some of the identified measurement requirements, no suitable sensing technique was in production. A discussion on investigation of these requirements is contained in the following section.

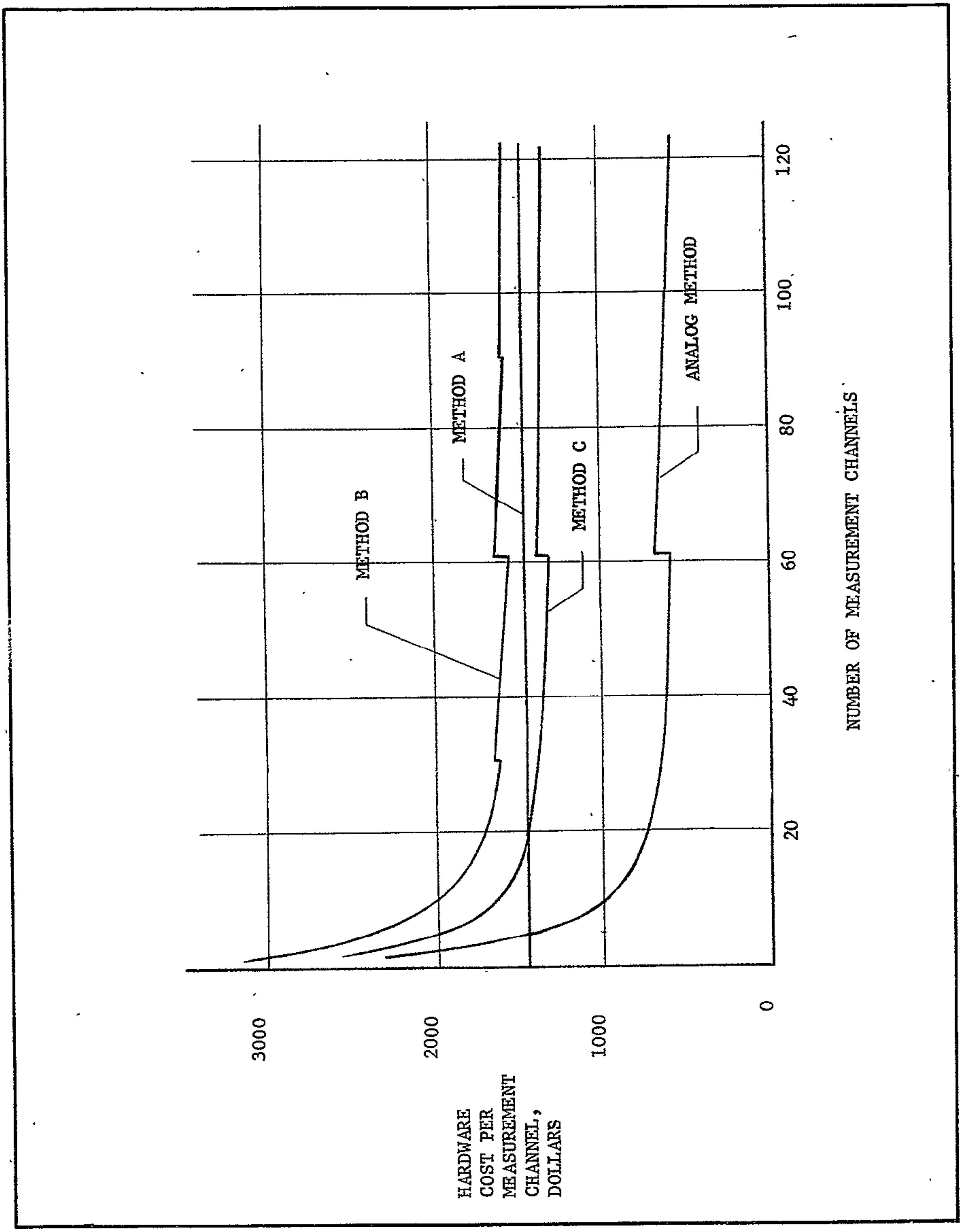


Figure III-7 Hardware Costs Per Measurement Channel

C. New Sensor Technology Recommendations

In the previous section, it was pointed out that there were some measurement requirements identified which are not readily met by application of existing sensors or developed sensor concepts with on-board equipment. The discussions in this section describe the investigations carried out to find solutions to these measurement requirements, and the resulting conclusions and recomendations. The references noted in these discussions are listed in Appendix A of Volume I.

1. Detection of Incipient Failures

Reference 3 reports thoroughly on a study of applicable sensing techniques for providing indication of component conditions, including incipient failure conditions. The less conventional techniques selected, implemented and tested on a Pratt and Whitney J57-P37A engine included:

a. Engine external and internal sonic and vibration analysis, utilizing high temperature piezoelectric accelerometers and microphones.

b. Bearing incipient failure detection, utilizing ultra-sonic-range accelerometers.

c. Lube system dynamic pressure monitoring by piezo-electric pressure transducers.

d. Combustion and turbine section temperature monitoring by electronic scanning of chromel-alumel thermocouples.

e. Lube condition and contamination monitoring, utilizing electrical resistance type filters and magnetic chip detection.

f. Turbine blade tip geometry monitoring by means of capacitive proximity transducers.

g. Spool acceleration monitoring by inductive pick-up.

Reference 119 reports a later investigation by Pratt and Whitney of existing commercially available equipment for acquisition of bearing signature data. Good results were obtained in the application of bearing vibration analysis to assess ball bearing cage condition and roller bearing race condition for the

RL10 rocket engine development program. Reference 66 reports on engine vibration monitoring by piezoelectric vibration transducers operating at 900°F on the Boeing 747 aircraft. H. L. Balderston reports extensively on studies by the Boeing Company on acoustic energy and acoustic emission phenomena for detection of incipient failures in structures, mechanical, hydraulic, electrical, and electronic subsystems (References 63, 64, 65 and 105.

Reference 121 reports on infrared and temperature sensing with fiber optic techniques. These techniques are expanded on, with discussion of actual application to turbine engine monitoring and control, in Reference 124. This reference describes the materials and construction features of an electro-optical system with an access window capable of withstanding high temperatures and pressures, fiber-optic transmission lines, filters and electronic/photoelectric sensing unit for measurement of spectral energy at specific wavelengths produced within jet engines. The existence of practical models of pyrometers using these techniques and applied to jet engine monitoring was confirmed through discussions with W. H. Marsh and B. H. Snow of General Electric's Aircraft Engine Group, Evendale Plant, Cincinnati, Ohio. A pyrometer built by this organization is being actively employed in development testing of the F 101 engine for the B-1 aircraft to scan turbine blade temperatures during engine operation. ±30°F RMS accuracy is claimed. This device has been employed for engine instrument tests for approximately five years. Mr. Snow may be contacted for further information. A similar device is built by Land, a British firm, for the Concordia aircraft now undergoing certification test.

2. Propellant Quantity Gaging

Liquid level sensing techniques are covered in many of the references. Reference 70 reports on laboratory investigations to determine the feasibility and limitations of a method which detects the change in resonant frequency of a tank excited by RF energy as the amount of fluid in the tank varies. Reference 74 discusses seven potential techniques for zero-g mass gaging. Reference 131 reports on a gaging system that computes propellant quantity consumed by an auxiliary propulsion system by measuring the duration of engine firing and compensating for transient flows when solenoid valves are energized. Reference 129 is a complete state-of-the-art survey of LO_2 and LH_2 propellant gaging; it was compiled as a part of the McDonnell Douglas Space Shuttle Phase B Study.

Contract NAS10-7258, "Propellant and Gases Handling in Support of Space Shuttle," includes a specific task to define

A propellant gaging system for Space Shuttle which represents an improvement over the Saturn V concept. This task was not complete at the time of this report.

3. Leak Detection and Hazardous Gas Concentration Monitoring

Ultrasonic leak detection techniques are reported in References 130 and 132. Reference 130 also recommends the use of a cabin gas analyzer (mass spectrometer) for hazardous gas concentration monitoring on the flight vehicle during atmospheric flight and for ground operations. Reference 118 reports on an analytical study of the recommended mass spectrometer, now being incorporated on a Skylab experiment (M171). Our study concurs in the recommendations presented in these references.

4. Ignition Detection

Ignition detection is needed to verify the lighting of torch igniters in the main engines. In the baseline engine, failure of one preburner to ignite can potentially result in backflow up the unignited path and cause an explosion. The only ignition detection systems we have been able to identify for this application would either employ light detectors (UV, IR or visible) looking through a suitable view window, or would detect ignition by means of detecting pressure rise. The ability to discriminate between the small differences in pressures between the ignited and non-ignited conditions is doubtful. A study to identify and assess alternate approaches for ignition detection is recommended. A potential approach that also should be investigated is the use of acoustic emission sensing. Boeing has demonstrated the use of this technique for detecting combustion of a torch, but only in a laboratory environment.

Additionally, there is no developed technique for assuring that, during igniter checkout, sparking occurs at the plug gap and not at some point between the exciter and the plug. We recommend that evaluations be conducted to derive a technique for accomplishing this function with on-board equipment. Potential techniques include signature analysis of igniter excitation current and discrimination of spark location by acoustic measurement.

5. Accurate Flowrate Measurement

Accurate flowrate measurement for rocket engines are presently accomplished with turbine flow meters. It is difficult

to verify the performance of such sensors prior to operational use. Gas spin-up test can damage the bearings of propellant-lubricated cryogenic flowmeters. One alternative technique is to use pump parameters to derive flowrate, but the resultant accuracy may not be sufficient. A simpler approach would be to derive flowrate from measurements of temperature and differential pressure. No sensor is available, however, that will accurately measure small differential pressures in high pressure systems.

6. Recommended Technology Investigations

a. Acoustic/ultrasonic techniques appear to hold much promise for resolving many fault detection/isolation/prediction requirements not amenable to conventional sensing techniques. Work by Boeing has shown acoustic emission to be a potentially good indicator of bearing incipient failures. Deflection measurement is a possible alternative or supplementary technique. Further work should be done to establish the feasibility of both acoustic emission and deflection measurement approaches in application to Space Shuttle propulsion system rotating machinery, and to establish the feasibility of applying acoustic measurement approaches to ignition detection and igniter spark location discrimination.

b. Ultrasonic Leak Detection for both internal and external leaks has been shown to be feasible, using a combination of contact probes and microphones. There is insufficient data, however, to show that state-of-the-art devices will work satisfactorily and maintain integrity with cryogenic temperature cycling and at Space Shuttle vibration and acoustic environment levels. We recommend technology work in these areas.

c. Accurate measurement of small differential pressures in high pressure systems cannot be accomplished with today's technology except in the laboratory. A study to define and assess approaches is recommended.

d. Igniter spark presence and location are not readily detected by any known technique which can be applied to on-board checkout. In addition to the recommendations presented in Paragraph a on the previous page, it is recommended that other approaches be identified and assessed.

tion current signatures to determine whether sparking is occuring at the spark plug gap, or at some point between the plug and the exciter.

7. Application of Sensing Techniques

Table III-3 presents a listing of sensor applications to the propulsion systems measurement requirements. Both commonly used and potential sensing techniques are listed. In application of these sensing techniques, the designers of mechanical devices must consider design for on-board checkout and monitoring as well as for function and for accommodation of stresses. Emphasis needs to be placed on design to enable redundancy verification and to incorporate the required sensors. Valves should be designed to incorporate built-in proximity sensors, fiber optics, or contact switches for detection of position of internal parts, and with provisions for ultrasonic contact probes to detect internal leakage. Bearing housings should be designed to accomodate acoustic sensors.

TABLE III-3

APPLICATIONS OF SENSING TECHNIQUES

APPLICATION	SENSING TECHNIQUE	REFERENCES
Detection of out-of-balance conditions in rotating elements	Sonic-Range Accelerometers	3,57,66
Detection of incipient failure in bearings, gears, and structural elements	Ultrasonic-Range Accelerometers	3,63,64,65, 116,119
Detection of internal and external fluid leakage, cavitation	Ultrasonic Transducer	65,105,116, 130,132
Temperature Measurement	Thermister, Resistance Wire	3,123
	Thermocouple	3,68
	Fluidic Oscillator	3,122
	Optical Pyrometer	121,124
Lube oil solid particle content measurement	Electrical resistance type monitoring filters	3
Flow rate measurement	Turbine-Type Flowmeter	*
	Vibrating Reed Flowmeter	122
	Positive Displacement Meter	*
	Heated Resistance Meter	*
	Fluidic Flow Meter	125,128
Pressure Measurement	Strain Gage Pressure Transducer	*
	Capacitive Pressure Transducer	*
	Piezoelectric Dynamic Pressure Transducer	3
	Optical Interferometer Pressure Change Transducer	69
	Bourdon Tube/Potentiometric or Variable Inductance Transducer	*
	Fluidic Oscillator	3, 122
	Fluidic Amplifier	3

* Vendor catalogs, standard instrumentation reference texts.

(continued)

TABLE III-3 (Continued)

APPLICATIONS OF SENSING TECHNIQUES

APPLICATION	SENSING TECHNIQUE	REFERENCES
Rotational Speed and Acceleration Measurements	Tachometer	*
	Inductive Proximity Sensor	3
	Strobotac	*
Axial and radial motion and clearances of rotating elements	Capacitive proximity sensor	3
	microwave signal attenuation	3
	Optical/photocell or laser	3
Linear or rotational analog position measurement	Potentiometer	*
	Variable inductance (LVDT)	*
	Variable capacitance	*
	Optical Encoder	*
	Syncro, Selsyn, Resolver	*
Discrete position detection	Contact switch	*
	Magnetic proximity switch	*
	Inductive or capacitive Triggering	*
	Optical/Photocell	*
Cryogenic liquid level detection	Capacitance probe	74, 129
	Heated resistance wire	129
	Optical refraction	129
	Float/Magnetic switch	127
	RF Cavity Resonance Sensing	70,74
Lube oil level measurement	Capacitance probe	3
	Heated resistance wire	*
Hazardous gas concentration detection	Mass spectrometer	97,112,118, 130
Flame detection	Boroscope/photocell	122,124
	Optical pyrometer	121,124
Ignition spark detection	Boroscope/photocell	122,124
	Ignition current analysis	
	Acoustic emission	

* Vendor catalogs, Standard Instrumentation Reference Texts.

IV. OCMS CONCEPT

IV. OCMS CONCEPT

IV. OCMS CONCEPT

A. OCMS APPROACH

The selected approach to Space Shuttle propulsion systems onboard checkout and monitoring is discussed in three sections. Criteria regarding the degree to which the checkout, monitoring, and evaluation functions will be performed by the OCMS are developed and presented in Section 1. Section 2 develops and describes the data management aspects of the OCMS approach. Section 3 describes the configuration, functions, and allocation of the Digital Interface Units which serve to interface the propulsion systems with the vehicle data management system.

1. Criteria

The following discussions develop and present criteria for OCMS functional capability and usage. These criteria establish the degree of performance of checkout, monitoring, and evaluation functions required of the propulsion OCMS for the various phases of the shuttle mission.

a. Preflight Checkout - The purpose of preflight checkout of the propulsion systems is to establish an acceptable level of confidence that these systems will perform satisfactorily in the next flight. This confidence may be obtained by any means that will detect existing or impending component failures, and hence reduce the probability that a failure exists or will occur during the flight. With factory acceptance testing, comprehensive inflight monitoring, postflight evaluation of flight performance, post-maintenance retest of replaced LRUs, and monitoring during ground servicing operations, considerable confidence that no failures exist or will occur in the next flight will have been obtained. In particular, the inflight monitoring necessary for fault detection and redundancy management, performed under actual operating conditions in the flight environment, provides a degree of confidence often unobtainable by ground test. In the case of propulsion system mechanical elements, sufficient confidence is expected to exist from prior operating cycles that no special preflight tests to functionally check mechanical subsystems are necessary. In other words, if this equipment performed correctly throughout all its previous normal operating cycles (without evidence of failure, degradation, over-stress, or approach of end of normal lifetime) then no significantly greater confidence that it will again perform correctly can be obtained by testing. In fact, since the stresses on propulsion subsystems are primarily self-induced, tests requiring actual subsystem operation would decrease system life. Dry-system functional tests would require considerable simulation, would not be realistic in the absence of normal stresses, and would provide little additional confidence

over that obtained by leakage checks, post flight inspections and by monitoring ground servicing operations such as purging and propellant loading. From this rationale, the following OCMS criteria statement was generated:

- Preflight checkout of mechanical elements of the propulsion systems will be limited to verification of correct initial conditions for start, and to monitoring of the start-up and operation of those subsystems which are started prior to flight.

The above rationale and criteria implies a high level of confidence that electronic equipment employed for inflight monitoring is in a flight-ready condition, i.e., there must be an acceptable level of confidence that in-flight failures and indications of impending failure will be detected and isolated. To achieve the requisite level of confidence, good design and integration of the sensors into the mechanical equipment is mandatory, and the electrical elements must be verified prior to flight. The electronics equipment, including engine controllers and DIUs, is amenable to rigorous self-test and can be employed to perform sensor electrical checks. Therefore, the following criteria will apply:

- Preflight self-checks of electronic subsystems and elements will be performed. These checks will include verification of sensor electrical elements.

The checking of sensor elements is defined to mean the verification of the correct sensor output for the static condition that exists during avionics preflight self-checking. This verification is expected to take a number of forms, namely:

- For open/closed position switches, verification will consist of continuity/voltage checks on the normally closed contacts for that condition, and a verification that the normally open contact is indeed open.

- Analog position indicators will be checked by verifying the proper voltage output for the static condition during self-check.

- Sensors forming a leg of a bridge network will be checked by verifying correct bridge output voltage at self-check conditions, and may include special sensor leg continuity checks and/or bridge self-checks which unbalance the bridge to a specific self-check output voltage

- Digital output transducers will be specified to include self-check provisions such that upon command from its associated DIU, the transducer will perform an internal self-check and report the results to the DIU with reserved self-test output codes.

- Sensors that respond to dynamic conditions will be self-checked during static conditions by continuity checks and will be checked against back-up parameters during start and/or operation of the subsystem. Sensors in this category include vibration pick-ups, flow meters, and angular velocity transducers.

Since ground servicing and checkout operations may produce equipment failures and will use up a portion of the life expectancy of time or cycle-sensitive components, sufficient parameter monitoring and evaluation is necessary during these operations to assure detection and isolation of any faults that occur and to record operating history when applicable. Since equipment will be provided onboard for these purposes during flight operations, it is logical to employ that same equipment for monitoring and evaluation of ground operations. Thus:

- Applicable system parameters will be monitored and evaluated by onboard equipment during ground operations for purposes of fault detection, fault isolation, and operating history recording.

b. <u>In-Flight Monitoring</u> - Performance and condition indicating parameters will be monitored and evaluated during and after engine start and in-flight for the following purposes:

In-flight ready-to-start condition verification
Emergency detection
Fault detection and isolation
Real-time trend analysis
Operating-state history
Performance data recording

A precept of this study was that all inflight monitoring would be accomplished by onboard equipment, without reliance on any inflight data interface between the vehicle and the ground.

Rationale and criteria establishing the extent to which each of the above monitoring and evaluation functions will be performed in flight is discussed in subsequent paragraphs.

c. In-Flight Ready-to-Start Condition Verification - In many cases, an attempted start of a combustion device under incorrect initial conditions can result in equipment damage or unsafe conditions. For example, an attempt to start an RCS engine with its bipropellant valves initially open or partially open would possibly result in the presence of an excessive propellant quantity in the thrust chamber at ignition, causing an explosion of the engine. In any case, an abortive start because of improper initial conditions will be wasteful of fuel, electrical power, and equipment life. For these reasons, the following criteria will be applied:

- Appropriate onboard monitoring and evaluation will be provided to verify, just prior to inflight start, that all applicable equipment and associated system parameters are in the correct conditions for start.

d. Emergency Detection - Emergency detection, for purposes of this study, is defined as the detection of any condition requiring automatic action (e.g., engine shutdown) to avoid a potentially catastropic effect or requiring special precautions or emergency procedures by the crew. Emergency detection capability must be sufficiently reliable to assure that the probability of an emergency condition not being detected is neglible. Further, any conditions requiring special precautions or procedural decisions and actions by the crew must be immediately displayed in a manner different from routing information. These considerations resulted in the following criteria:

- Emergency detection provisions must be redundant.
- Redundant caution and warning display capability will be provided for the following conditions:

  Loss or impending loss of major functions (main engine, airbreathing engine, separation, etc.)

  Flight Safety parameters exceeding safe limits.

  Loss of redundant elements.

  Hazardous leakage.

e. Fault Detection - In addition to detection of emergency conditions, inflight fault detection is necessary to know when to switch to a redundant element. Further, inflight fault detection is desirable to allow any required maintenance resulting from a flight to be identified without resort to ground tests. Fault isolation for maintenance is aided by inflight detection. Also, some incipient failures and transient or intermittent faults may

be difficult or impossible to detect by ground tests because of inability to accurately simulate flight conditions. Therefore:

- Provisions will be made for inflight detection of failures (including out of specification performance, incipient failures, and transient or intermittant faults) for all identifiable failure modes for which suitable onboard detection techniques and equipment are practical.

f. Fault Isolation - In many cases, the operating conditions and actual sequence of events before, during and after a failure must be known in order to discriminate between cause and effect. Also, transient or intermittent faults may not be isolatable in later tests without resorting to highly realistic simulation of conditions and events. In some cases, fault isolation must be accomplished immediately after detection, to identify lost redundancy and to initiate the proper corrective or safing action. Further, it is desirable that post flight tests for determination of maintenance requirements be avoided. These considerations have led to the following criteria:

- Data for fault isolation will be acquired in flight, by onboard equipment.

- Diagnosis for fault isolation will be accomplished with onboard equipment. This diagnosis will relate any faults to the required maintenance, and record on the vehicle maintenance recorder the data necessary to provide postflight printout of the identified maintenance requirements.

- Fault isolation will be accomplished as soon after detection as is necessary to identify lost redundancy and to initiate corrective or safing action when applicable. In cases when no LRU-level redundancy exists and where corrective or safing action is taken in response to failure detection only, as in the case of ACPS engine emergency shutdown, diagnosis for fault isolation may be performed on stored data at a later time. Preferably, this type of diagnosis will be accomplished prior to landing, but may be delayed until after landing if necessary.

g. Real Time Trend Analysis - Real time trend analysis is defined as any analysis of equipment condition, performed concurrent with or immediately after the operation of that equipment,

for the purpose of recognizing symptoms of impending malfunction. Effective trend analysis on any equipment item depends on a thorough knowledge of the modes of failure of that item and the detectable symptoms, if any, that precede or accompany the inception of failure. Impending or incipient failures may be evidenced in many different ways, each requiring a different analysis technique. All such techniques require data extrapolation; comparison with models, reference signatures, tolerances, or past data points; probability matrix solutions; or combinations of these and other techniques such as computation of moving averages, moving ranges, etc. Techniques must therefore be suggested by and adapted to the specific symptomatic effects evidenced by individual equipment items. The techniques for trend analysis are costly in terms of processing loads and computer memory capacity, therefore:

- Real time trend analysis will be performed only for those failure mode cases where it would result in avoidance of significant damage or in early initiation of precautionary action to cope with an impending emergency condition.

Non-real time trend analysis, performed on recorded performance data, is discussed under the subject of Performance Data Recording, in paragraph i below.

h. <u>Operating Histories</u> - Where a strong correlation exists between an LRU's performance and its operating history (i.e., the variance of operating history before failure is small), replacement based on operating history is an effective way of increasing mission reliability. This is a particularly valuable approach in cases of identical redundant LRUs having a strong correlation of performance with operating history. The stronger the correlation, the higher the probability that all of the identical units will fail during the same flight. Therefore:

- Where correlation exists, or is likely, between an LRU's performance and its operating time, stresses, number of on/off cycles, number of revolutions of strokes, or combinations of these, a history of operation of the LRU will be maintained in computer storage so that when an LRU's operating history exceeds the limit for that LRU, a post-flight printout will provide notification of required replacement. These operating histories will not be continuous, but will be periodic or on-condition updated totals of accumulated time, cycles, etc.,

at discrete states (on, standby, NPL, MPL, etc.) or discrete stress levels (20% overtemperature for example).

i. Performance Data - In the discussion of preflight checkout in paragraph "a" above, criteria were developed to limit the extent of preflight checkout of mechanical elements of the propulsion systems. This limitation was based on ability to assure a sufficient probability of mission success by other means, including verification of flight performance. Much of this verification is accomplished by automatic inflight evaluation as discussed in previous paragraphs. However, the need for extensive computer processing capacity, as well as the need to rely on human intelligence for many performance evaluation tasks, makes comprehensive inflight evaluation of performance reasonable. A previously stated precept is that no inflight vehicle-to-ground interface for performance data transmission will be provided. The Electronics Design Reference Model, however, assumes maintenance recording capability sufficient for storage of propulsion systems flight performance data. Recorded flight performance data may be evaluated after the flight to verify inflight diagnosis, identify incipient failures, identify and analyze trends, and obtain data for design improvement. Therefore:

- Propulsion systems flight performance data will be acquired and recorded on the vehicle maintenance recorder to enable postflight evaluation for verification of inflight diagnoses, identification of incipient failures, and identification and analysis of trends.

j. Post Flight Evaluation - The onboard equipment for inflight control and monitoring inherently provides the capability for ground control and monitoring for servicing operations such as purging and propellant loading. It also provides processing capability, mass storage, and recording provisions that can be used for ground data processing. Due to safety considerations during hazardous operations, and possible crew-compartment congestion from personnel engaged in maintenance and servicing operations, control and display capability external to the vehicle will be required for many ground operations. For these reasons, the following criteria were developed:

- Inflight type monitoring and evaluation will be continued until completion of shutdown operations. Servicing programs then will be loaded into the onboard computers, replacing the flight programs. Flight-recorded data will be sorted, edited, and evaluated by the onboard computer complex to

produce maintenance printouts, trend analysis results and performance data records, catagorized by suitable equipment groupings (such as main engines, airbreathing engines, APS thrusters, etc.)

- Suitable ground connections to the vehicle data bus will be utilized to provide for transmitting commands and data between ground remote control and display provisions and the vehicle central computer complex.

k. Maintenance Retest - One of the assets of the onboard checkout and monitoring system is that it permits the elimination of a large part of the ground support equipment that is traditionally required for ground maintenance operations on electronic flight equipment. This is accomplished by using the onboard checkout equipment for retest of replaced propulsion units, in addition to the self-check of any replaced onboard checkout units. When maintenance is required on the onboard checkout equipment, that equipment will be retested before any replaced propulsion elements are retested.

- Maintenance retest of replaced LRUs employs the onboard checkout function to automate the retest procedures and to minimize the ground support equipment requirements.

l. Control and Checkout Processing Integration - The traditional checkout processing concepts apply to the OCMS until the start-up procedure is initiated or after the shutdown of a subsystem is complete. During actual operation of a subsystem, however, the checkout function and the control function become very intermingled. This intermingling is well illustrated by the Control Sequence and Logic diagrams presented in Volume II of this report. In addition to the monitoring required for closed-loop control, parameters are monitored and processed for control of redundancy and for emergency shutdown initiation. In order to determine data processing requirements for active subsystems, criteria relating the processing of checkout and monitoring functions to the processing of control functions had to be established.

Three possible ways of processing checkout functions in conjunction with control processing were investigated, using a single example control problem. The example problem is concerned with a thruster having a valving arrangement such that several valves must be opened in sequence to operate the thruster. It was assumed that backup capability exists in the form of redundant thrusters for use in case of malfunction of the first. One approach to control and checkout processing for this example is to allow the control processing to be independent of checkout

processing, doing its own logical checking to assure it is functioning properly. The checkout function then becomes a monitoring of the control processor's activity. This approach is illustrated in the flow chart of Figure IV-1.

A second approach is to let the control processing simply sequence the thruster on and verify that it is running, while the checkout processing runs independently to monitor actual signals and set a No-Go indicator if necessary. Under No-Go conditions one of the processors, controller or checkout, must determine the redundant status of the system and initiate a new sequence if possible. This approach is illustrated in the flow chart of Figure IV-2.

A third approach is to combine the checkout and control processing into one sequence as shown in Figure IV-3.

These three alternatives indicate that there must be some center of responsibility for correct overall system operation. It is not the normal control function to provide data management, yet this will be required if the control function is to catalogue and utilize the redundant capabilities of the hardware. Likewise, it is not a normal checkout function to interpret commands and perform actuation of hardware in response to those commands. But, as shown in the first two alternatives, the checkout function must at least know what should be done in response to these commands. The approaches which separate checkout and control processing require that both processors need to know the entire control sequence. Also, since the control function and checkout function must operate together, there must be communications between the two. This indicates approximately twice the data processing storage requirements of the integrated approach.

The conclusion drawn is that the most efficient approach toward onboard checkout of active subsystems is to integrate the control function and the checkout function. Therefore:

- Control and checkout will be treated as a single function for purposes of computer processing.

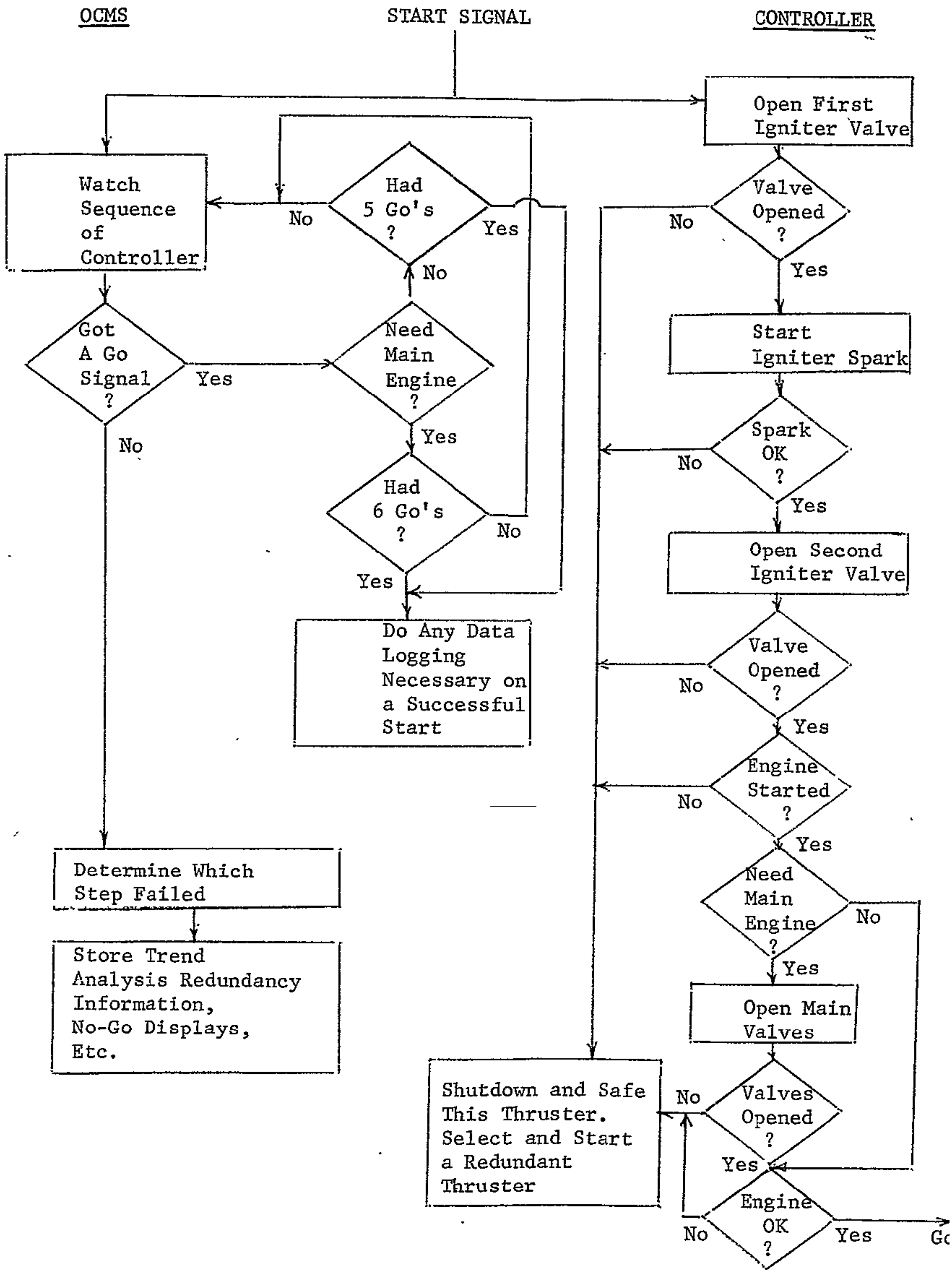


Figure IV-1 Checkout and Control Processing Approach 1

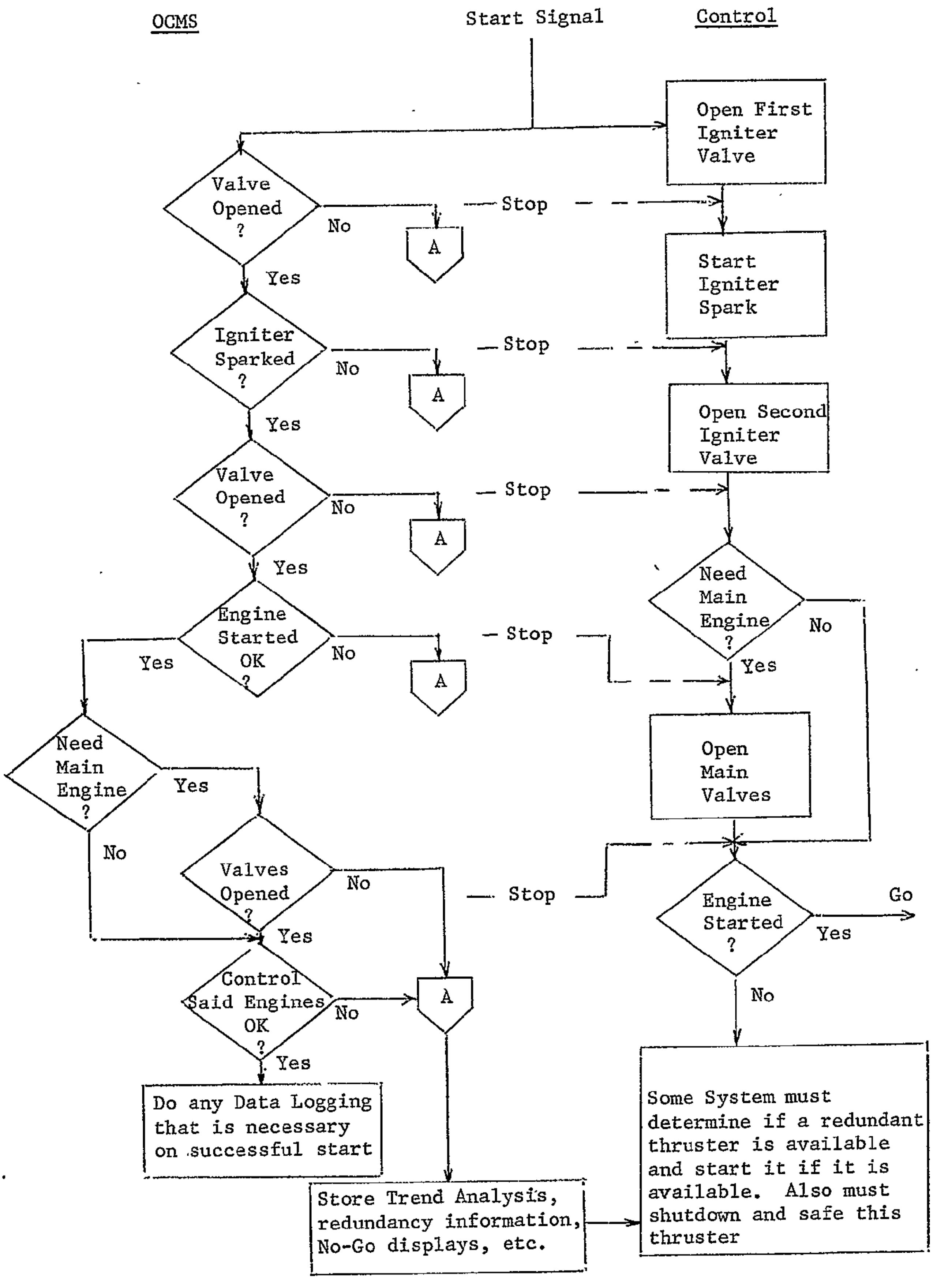


Figure IV-2 Checkout and Control Processing Approach 2

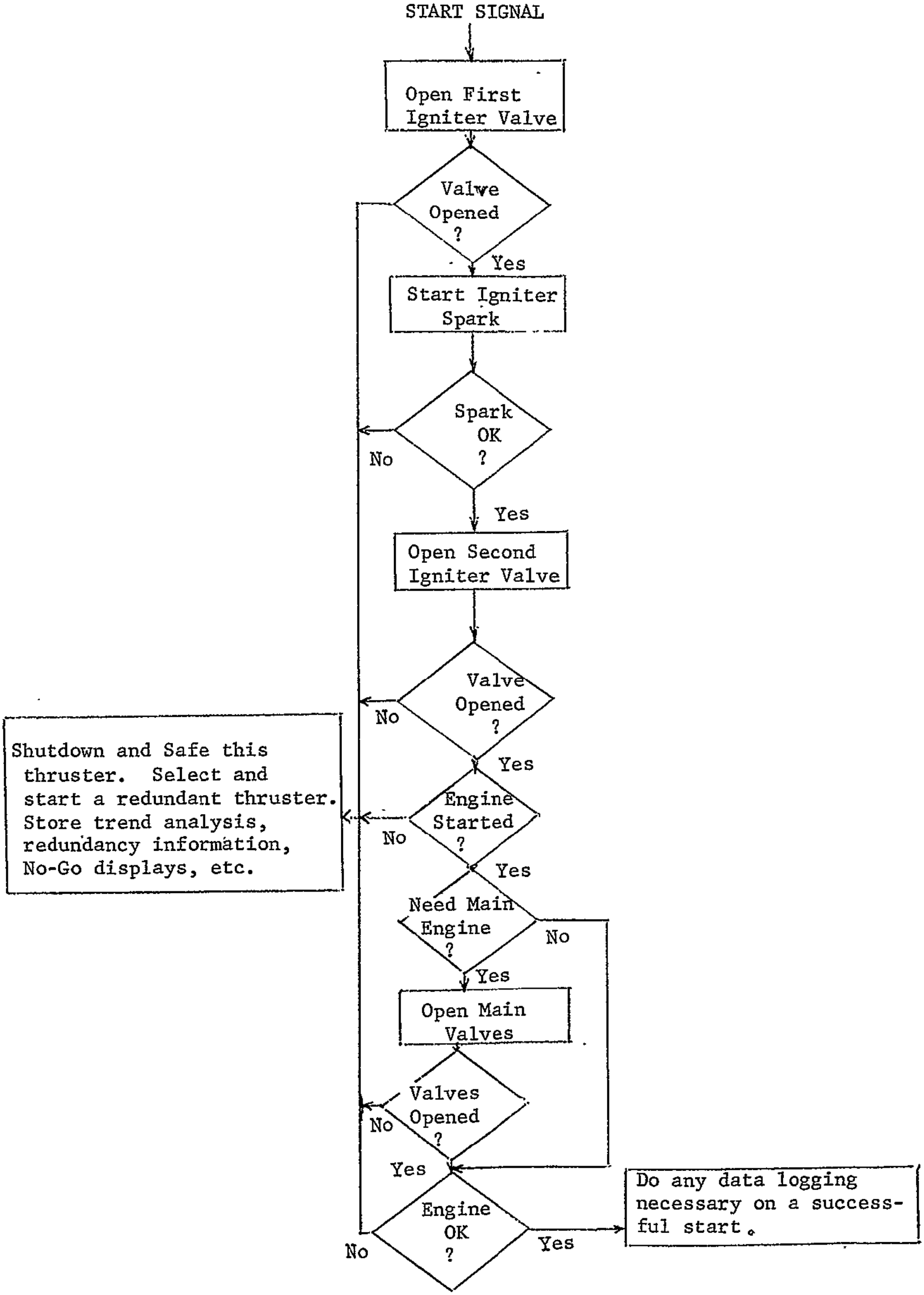


Figure IV-3 Checkout and Control Processing Approach 3

2. Data Management

The following paragraphs describe the data management elements of the electronics design reference model and the relation of each to the overall system. In the interest of attaining maximum continuity in this section, some of the information presented in the Electronics DRM (Volume II, Chapter II, Section D), will be repeated here.

Figure IV-4, DRM Electronics System, is a block diagram of the non-redundant electronics model. Redundancy is discussed in subsequent paragraphs. This particular model was chosen because it is a straightforward concept that satisfies the basic criteria of using a data bus system to eliminate the massive wiring harnesses of a point-to-point system, and achieves maximum system flexibility with minimum remote hardware. The resultant vehicle data bus traffic and computer processing loads are relatively high as shown in Section B of this chapter. An evaluation of the overall vehicle requirements will be necessary to ascertain the desirability of a modified model to preclude a data bus or processing limitation.

a. Central Computer Complex - As suggested by the size of the block representing the vehicle control computer complex, it is the key figure in this system. All propulsion checkout and monitoring functions, with the exception of those accomplished by the engine controllers, are under the direct supervision and control of the central computer complex (CCC); it is a selective, specific response on-demand system. All actions are initiated by the CCC, and only at the time they are needed. There is no cyclic or multiplexed data acquisition or distribution sequence. All data bus communications are between the CCC and the remote units, never between two remote units. For the purpose of estimating computer processing loads, it is assumed that the CCC would have a processing speed of 2 microseconds per instruction.

It was further assumed that each central computer has a memory size of 64K thirty two bit words. It is estimated that the propulsion function would require approximately 9K of the central computer's core memory if the software was implemented in assembly language.

b. Data Bus - The digital data bus is the communication link between the CCC and the remote digital interface units. From the peak data bus traffic estimates developed in Section B of this chapter, each data bus has been defined as a one megabit, biphase, twisted pair bus.

c. Digital Interface Units - The digital interface units (DIUs) are the system elements which provide the interfaces

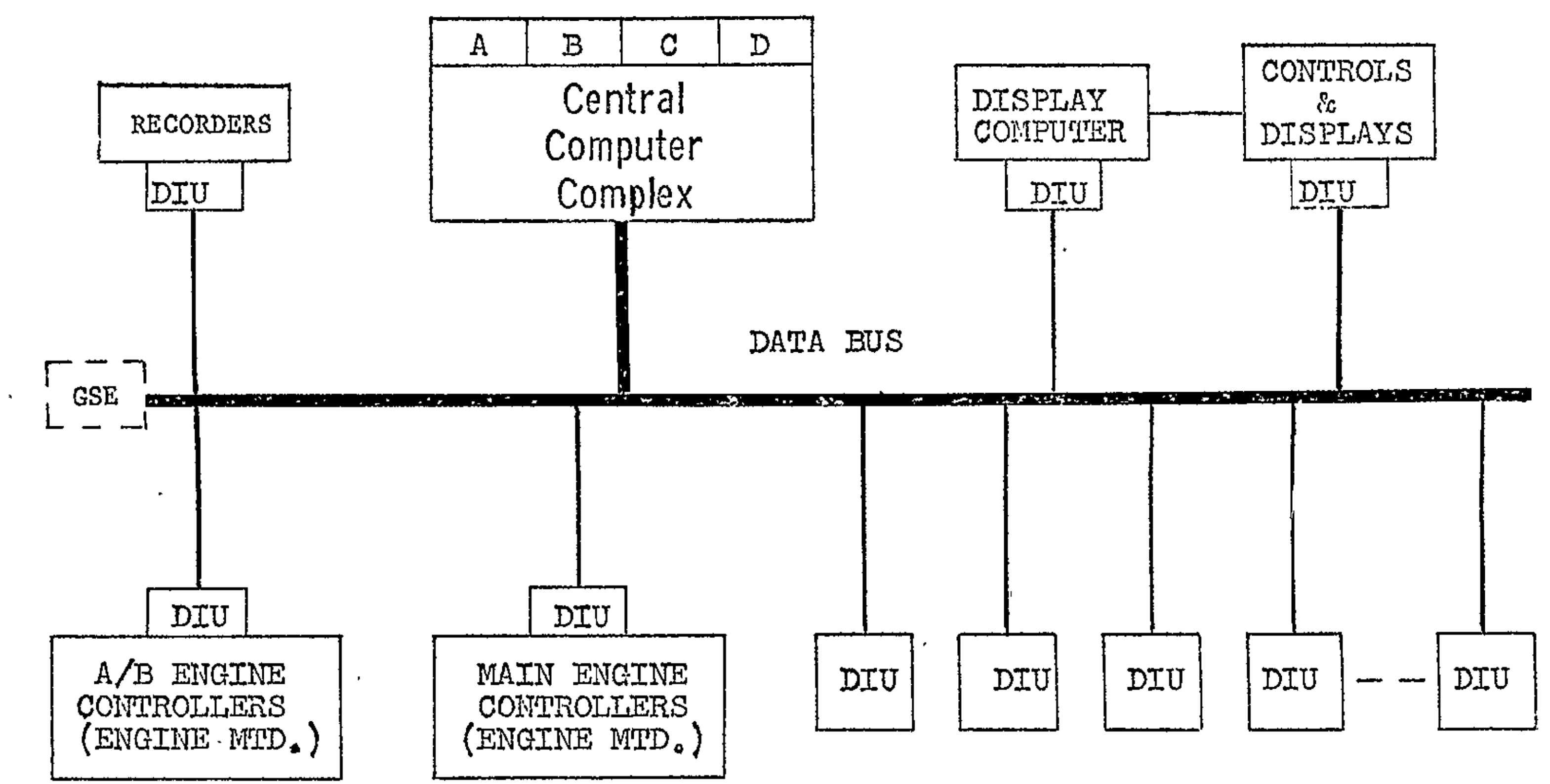


Figure IV-4 DRM Electronics System

between the digital data bus and the propulsion system elements, or peripheral units such as the recorders, display computer, and the crew control and display panel. Those DIUs which service the propulsion elements perform functions including:

> Control - decode digital commands from the CCC and generate stimulus for a propulsion element, typically in the form of a discrete voltage.

> Data Acquisition - select the desired signal input from the decoded measurement request, signal condition the input as required, convert analog signals to digital data and format the digital data into intelligible responses to be reported to the CCC.

In addition, the DIUs are required to be self-checking so that faults may be isolated between the electronic elements and propulsion elements of the system. DIUs are internally redundant only to the extent that no single failure will result in the erroneous execution of a critical function (e.g. close a fuel isolation valve during main engine operation), and that the data bus interface circuitry is quadruply redundant. They have been identified in this manner to simplify the self-check requirement as well as for reasons discussed in the DIU allocation criteria of Paragraph 3 below.

The DIUs are under the power control management of the CCC and are powered down when not in use; e.g., OMS engine DIUs are not powered up on a Ferry flight. DIUs accept standard vehicle power (28 ± 4 VDC) and condition that to satisfy only its own power requirements. Circuit breakers provide back-up power control to provide emergency shutdown capability and to facilitate maintenance operations.

d. Remote Processors - The engine controllers for the main and airbreathing propulsion systems are discussed in depth in Volume II, Chapter II, Section D, and will not be further discussed here. The data management DRM treats those engine controllers like any other DIU. The display and recording requirements are presented in Section C of this chapter. The GSE functions are also discussed in this chapter.

e. Communications Sequences - The communication sequence between the CCC and a DIU is shown below and is described in ensuing paragraphs.

1. Command a DIU to Execute an Action
   a) CCC to DIU: Instruction for action
   b) DIU to CCC: Recirculate for verification

2. Data Acquisition
   a) CCC to DIU: Measurement request
   b) DIU to CCC: Recirculate for verification
   c) CCC to DIU: Data request
   d) DIU to CCC: Transmit data

To command a digital interface unit to perform as action (such as closing a valve) a four byte command is sent, and recirculated back to the CCC in formats described in Table IV-1.

To acquire data from a DIU (such as a line pressure) a four byte command is sent to the DIU and recirculated. After an appropriate time delay to allow the DIU to make the measurement, a three byte data request is sent to the DIU which returns data (typically in four byte format) rather than recirculating the command.

To obtain the regularly scheduled engine controller information (discussed in the previous section), a three byte command is sent to the engine controller DIU and the information is returned using as many bytes as necessary (within the format limitation) to return that particular set of information. The information sent from an engine controller is grouped by the frequency at which it is sent (for example, all data sent at a rate of 10 times per second is sent in one transmission).

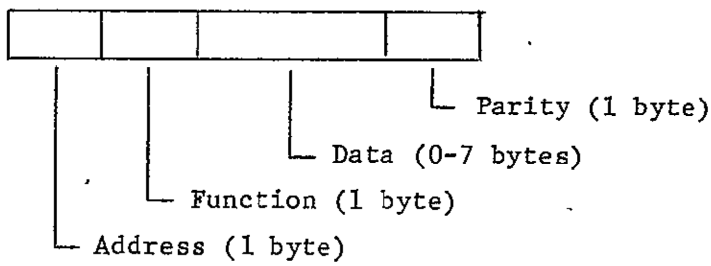
Information that can be grouped will be available in one transmission rather than in separate transmissions. Such block data handling techniques have been defined for the engine controllers and can be employed by the other DIUs, either if sequencing capability is added to the minimum hardware unit, or if the data being acquired is in digital form at the DIU input. Where the DIU inputs are analog voltages requiring analog to digital (A/D) conversion, the extra step to add sequencing is inexpensive considering the resultant reduction in data bus traffic, since the DIU needs a clock for the A/D converter anyway.

f. Redundancy - To satisfy the electronic system fail-operational, fail-operational, fail-safe redundancy criteria, the model presented in Figure IV-5 was defined. The basis for the OCMS redundancy philosophy is the concept of using an element of the system until it exhibits an indication of abnormal

TABLE IV-1

DATA BUS FORMATS

CCC to DIU

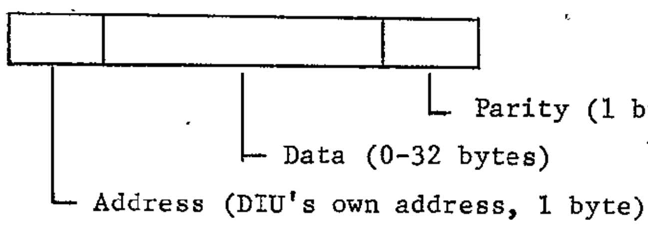


This format is sent to the DIU's for two reasons:

1) Command the DIU to some action (stimulate, perform a measurement, self check, etc.); in this case the message is recirculated back to the CCC in its entirety.

2) Request data (sent after a DIU has had time to make a measurement per a command); in this case the DIU returns a data message as shown below.

DIU to CCC



This is the format used by the DIU's to send measurement data to the CCC, and is also the format used to send information from an engine controller via a DIU.

NOTES: Each byte is nine bits long; 8 bits data, 1 bit parity.

A DIU cannot initiate a transmission. It must receive a message from the CCC (of the top format above) which it will respond to with the data it has to transmit.

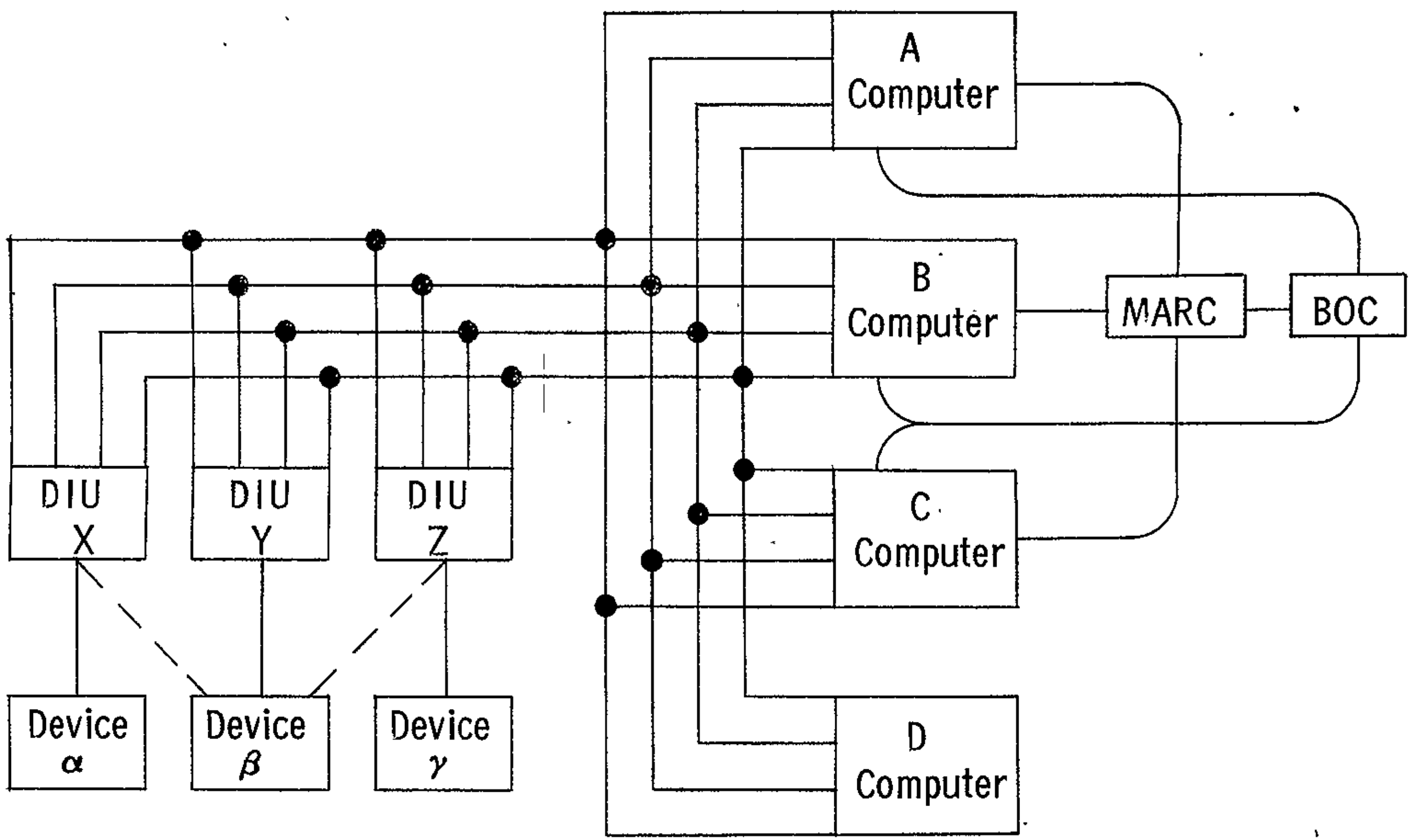


Figure IV-5 DRM Electronics Redundancy

operation, then switching to a redundant element. This technique lends itself to simplicity of operation and easily defined system control. It also implies a requirement for a high level of confidence in the ability of the system to identify anomalies in operation. This requires a high degree of reliability in the checking elements and the self-test procedures of the system, as well as a thorough knowledge of the failure modes of the system elements. However, this requirement is less severe than in the case of simultaneously operated redundant elements using voting techniques.

The redundant model consists of four vehicle computers, four vehicle data buses, four power buses, and a number of DIUs that is compatible with the redundancy and criticality of the corresponding propulsion elements. Although all four computers are assumed to be available and are always connected to the data buses, only three would be required by the system for compatibility with the propulsion DRM. For this reason, the redundancy model shows three computers connected to the comparator circuit (MARC) and to the bus output control circuit (BOC). The fourth computer could be assigned entirely to non-propulsion activity until such time that one of the other three failed. At that time, the fourth computer would be reloaded and brought into synchronization with the other two, to replace the failed unit. If effective use cannot be made of the fourth computer when it is not required for propulsion duty, or if the reload and synchronization process proves cumbersome, then the following discussion would be extended to include all four units.

The health of the three units performing propulsion functions is assessed by a memory access register comparator (MARC) which compares the contents of that register between all three computers; and by computer self-checks. Since all three computers run the same programs and are synchronized by a common clock, the contents of all three registers will be identical, barring errors. Therefore, by monitoring those registers with MARC, a defective computer, or a defective comparator element, would be identified and isolated from the system. Figure IV-6 shows the logic for MARC decisions.

While all three computers perform the same functions, only one has output bus control at any given time, and is designated the command computer by the bus output control circuit (BOC). Computer status, as determined by MARC, is the basis on which the command computer is selected. In the event of a computer failure, command status would be transferred to the next logical

MARC Status 1	MARC Status 2	MARC Status 3	Bus Control	System Status
OK	OK	OK	A	All OK
OK	NO	NO	A	C Failed
NO	OK	NO	A	B Failed
NO	NO	OK	B	A Failed
OK	OK	NO	A	3 Failed
OK	NO	OK	B	2 Failed
NO	OK	OK	C	1 Failed
NO	NO	NO	As Is	Unknown

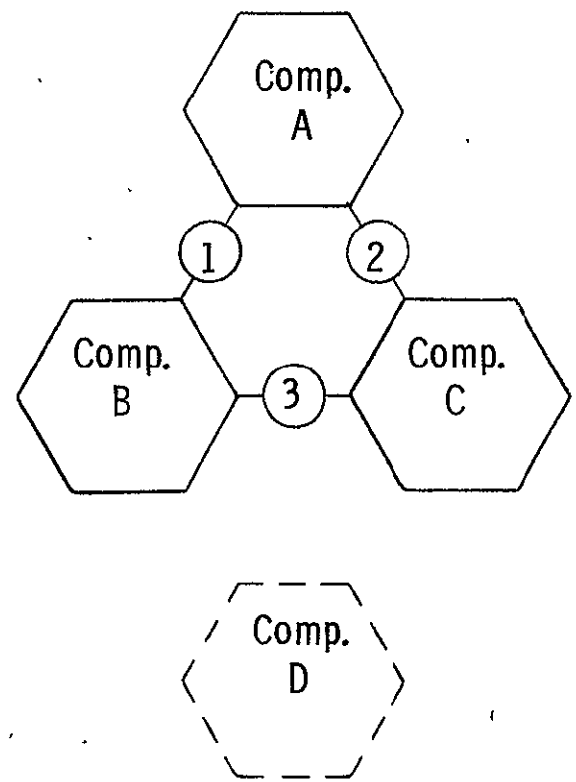


Figure IV-6 Memory Access Register Comparator Logic

unit. The suspected unit would be self-checked and, upon failing that, would be replaced by the fourth unit. Should the suspected unit pass the self-check, it would be re-synchronized and given an oppurtunity to continue operation. At the next demonstration of abnormality, the suspected unit would be replaced and removed from further operation.

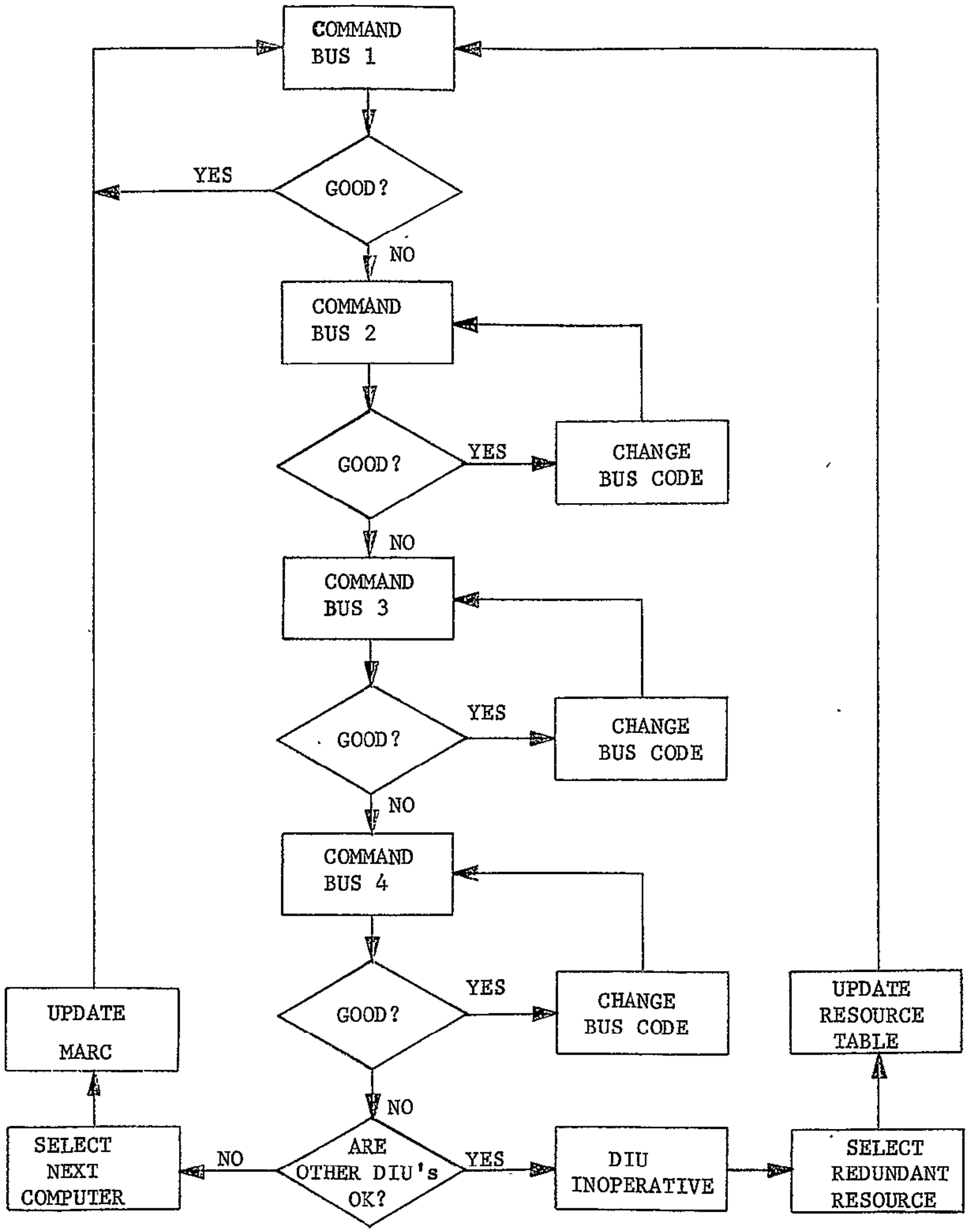
In the event of a second computer failure, the two remaining units would continue to be monitored by MARC, with the results of a self-check acting as the principal referee in case of disagreement between the two units. In addition, crew selection capability would be provided to execute an override if deemed necessary. The criteria for the crew's decision would be embodied in the rationale that, if all indications are normal at the time of computer disagreement, leave it alone.

MARC's output circuit to the bus output control circuit is required to be latching, such that a failure resulting in the loss of MARC's decision-making capability would leave the system in the last selected command state.

The four vehicle data buses are used in a fashion similar to the use of the central computers. The buses are used one at a time until an abnormal indication is exhibited by the first bus, then operation is switched to a redundant bus. The logic for this process is shown in the flow chart of Figure IV-7.

DIU redundancy is handled in an analogous manner, except in this case the system has the benefit of DIU self-check to assist in the decision-making process of determining whether or not a DIU is defective and should be replaced by a redundant unit. In cases where redundant DIUs do not exist, those DIUs would have been servicing redundant propulsion elements, hence the next level of redundancy would be called into service by commanding a redundant, DIU-propulsion unit.

g. <u>Data Processing</u> - The computer processing requirements were analyzed and it was determined that for data bus control, 37 CCC instructions were required to send a command to a DIU and 31 instructions were required to obtain information from a DIU. Thus, to obtain a measurement from a DIU, a total of 68 instructions must be executed to send the commands, receive the data, and to verify the correctness of the transmissions. The makeup of the 68 instructions is as follows:



NOTE: Good? = Responds correctly with the proper address?

FIGURE IV-7 DATA BUS SELECTION LOGIC

- 5 instructions to initiate a measure command
- 5 instructions to initiate a data retrieval command
- 12 instructions to handle the command Input/Output request
- 13 instructions to handle the data Input/Output request
- 20 instructions to receive the recirculated command and verify its source as correct
- 13 instructions to receive the data and verify that it was obtained from the correct source

The actual checkout programs are assumed to consist of, on the average, 20 instructions for each command given or measurement taken. This is based on having straight-forward assembly language programs doing the checkout function. It does not take into account any system overhead which may be required by the CCC.

This approach imposes the highest load on the data bus of any system that was evaluated. This is because each logical data transfer requires 4 transmissions:

CCC to DIU - setup for measurement

DIU to CCC - recirculation for verification

CCC to DIU - request data

DIU to CCC - send data

Also, since there is no fixed transmission cycle, the processing load is heavy because each message must be formatted each time it is sent. However, this system gives significant flexibility since any DIU can be contacted at any time; also, it is the simplest in terms of hardware since the DIU need only respond to its address and requires no data buffer. The CCC Data Bus Control is simply an Input/Output device, not a timing or multiplex device. Additionally, since the address is checked on every transmission, the error detection techniques will be the simplest possible.

In summary, the data management system results in a checkout and monitoring function characterized by high data bus loads and high control processor usage, but also with good system utilization, maximum flexibility, and a minimum of remote hardware. The data bus traffic and computer processing estimates of Section B of this chapter are based on this system.

h. Recommendations - A number of other approaches were given consideration in this study, each with advantages and disadvantages as compared with the reference model. The following items (which depart from the highly desireable characteristics of the model only to the extent of adding a small amount of hardware) are recommended for adoption in the final OCMS design for the stated reasons:

1. Incorporate sequencing at the DIU level to accomodate block data transfer capability for analog sensor outputs which lend themselves to this technique. This would result in reduced data bus traffic and somewhat reduced processing loads. It would also simplify the communication sequence required to perform a DIU self-check.

2. Incorporate a DIU interrupt scheme. This would consist of a unique interrupt line from each DIU to the central computer. A number of benefits would result:

a) In the design reference model system, the central computer is required to execute a time delay of appropriate length after it has given a DIU a command to perform a measurement. At the end of that time delay, the CCC may then request data from the DIU. If a DIU interrupt were available, it would be used to signal the completion of a measurement to the central computer, thereby relieving the CCC of the processing required to execute a time delay while waiting for a DIU to complete a measurement.

b) In the model system, the engine controllers rely on special codes which are inserted (in response to transmissions) to signal an anomaly in engine operation. These responses are possible only at the times that they are scheduled by the CCC. By adding an interrupt system, the engine controllers could immediately notify the CCC of an anomaly in engine operation. This would add another layer of caution and warning redundancy, since the interrupt system would be independent of normal communications on the data bus system.

c) In the reference system, each piece of data that is acquired by the DIUs must be evaluated by the CCC to determine whether or not that data is within specified limits. By adding hardware comparators to the DIUs, in addition to an interrupt system, the DIUs would be capable of evaluating acquired data. Then, instead of transmitting the data over the data bus system, the DIU could report go status via the interrupt line. This would result in a significant reduction in data bus traffic as well as CCC processing load.

3. DIU Allocation.

Subsequent to definition of the OCMS measurement requirements and location of the measurements on working schematics, the measurements were allocated to 25 DIUs of five basic types for the orbiter. The following criteria were used:

a) DIUs are located as near as possible to the associated propulsion element(s) to minimize wire lengths.

b) DIUs are at least as redundant as the associated propulsion elements.

c) DIUs shall possess as much commonality and interchangeability as possible.

d) Engine controllers are considered to be DIUs.

e) Redundant DIUs are physically separate to guard against catastrophic loss of total capability.

f) Sensor redundancy is based on the same criteria as DIU redundancy in addition to the criticality of the associated propulsion parameter.

The 20 DIUs (plus the five engine controllers) thus identified are described as follows:

Equipment Serviced	DIU Numbers	Redundancy Arrangement
Forward RCS engines and forward APS propellant management.	1, 2, 3	Each DIU services one RCS engine per engine module, for a total of 5 engines per DIU. In addition, each DIU services all of the forward APS propellant management equipment in a triply redundant arrangement.
Aft RCS engines and APS propellant management.	4, 5, 6	Same as for DIUs 1, 2, and 3, but for the aft equipment.
OMS engines	7, 8	Each DIU services all 4 of the OMS engines on a primary/backup basis.
APS propellant conditioning.	9, 10, 11	Each DIU services one section of the triply redundant subsystem.

Equipment Serviced	DIU Numbers	Redundancy Arrangement
Airbreathing engine propellant management	12, 13, 14	Each DIU services one section of the triply redundant subsystem. All three service the quad feedline valves to the engines on a primary/backup basis.
Aft main propulsion	15, 16, 17	Each DIU services the same parameters in a triply redundant arrangement.
Forward main propulsion.	18, 19, 20	Same as for DIUs 15, 16, and 17, but for aft equipment.

The DIU allocation is shown in diagram form in Figure IV-8. The quantities of measurements of different types serviced by each DIU are shown within the block representing the DIUs. "L" indicates position measurements; "P" pressure; "T" temperature; "V" voltage; "I" current; "Q" quantity; and "O" other.

Detailed allocation of measurements to DIUs for the orbiter are included in the measurement requirements tabulation, Table A-1, Appendix A.

By applying the same allocation criteria to the booster, the following allocations were made for each boom:

DIU Numbers.	Equipment Serviced
1, 2, 3	RCS engines and forward APS propellant management.
4, 5, 6	Forward separation engines.
7, 8, 9	Hydrogen or oxygen conditioning subsystem.
10, 11, 12	Aft separation engines.
13, 14, 15	Auxiliary power units.
16, 17, 18	Aft main propulsion system (other main propulsion system split among other DIUs)

Redundancy arrangements on these DIUs is the same as for parallel units on the orbiter. The total complement of booster DIUs is 57, i.e., 18 per boom x 2 = 36, + 7 airbreathing engine controllers, + 14 main engine controllers.

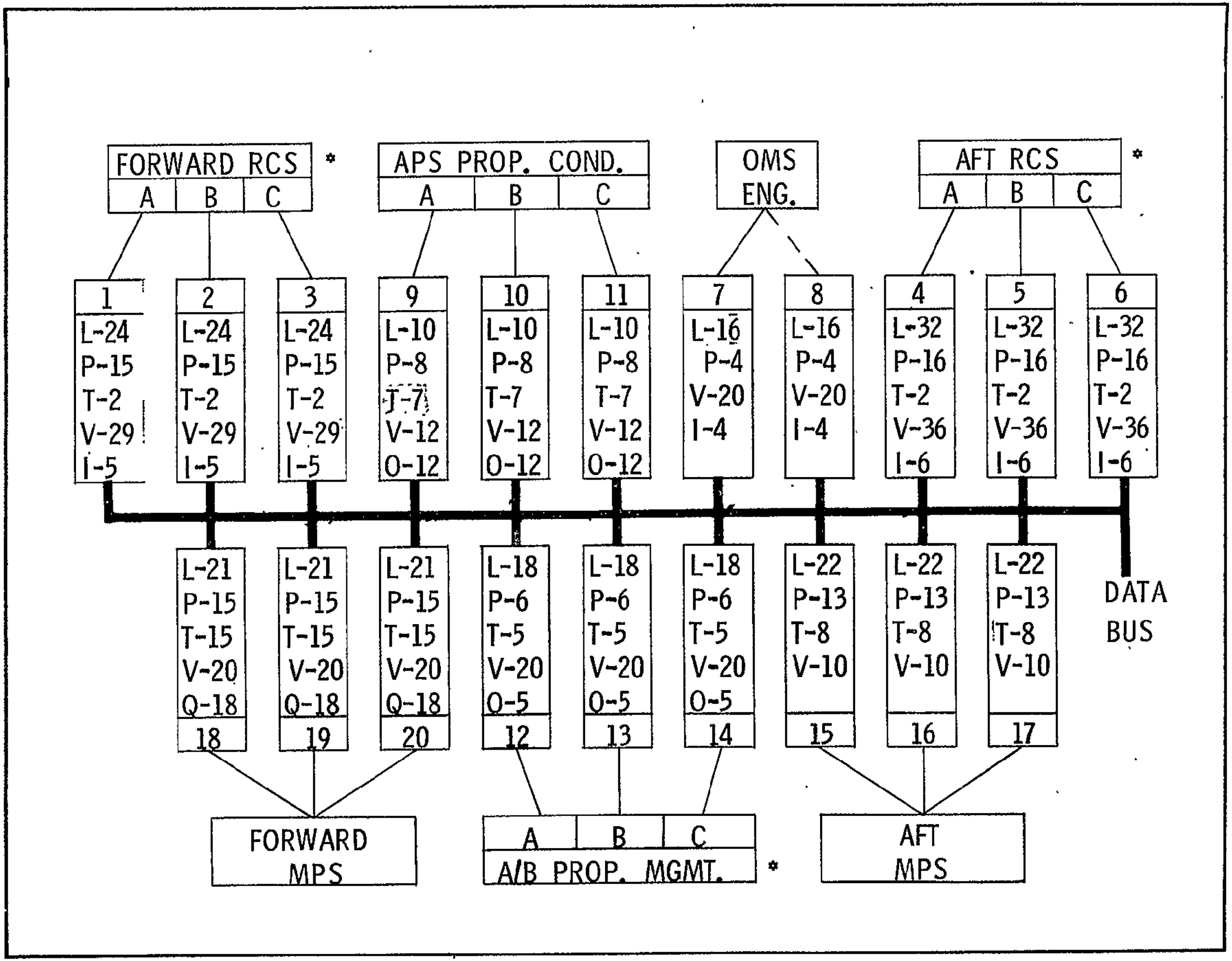


Figure IV-8 Orbiter DIU Allocation (less engine controllers)

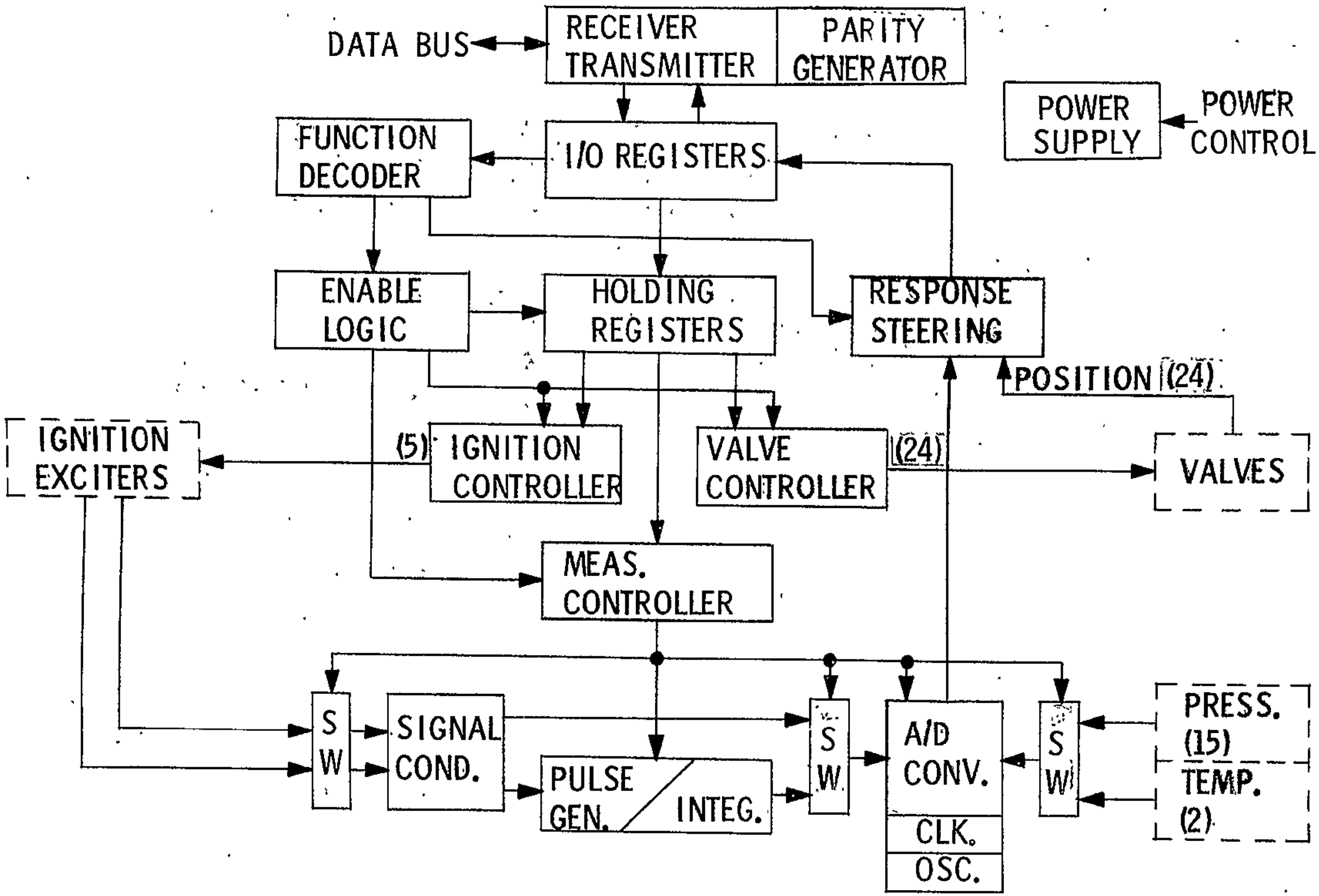


Figure IV-9 Sample DIU - Simplified Block Diagram

B. DATA BUS TRAFFIC AND PROCESSING LOADS

The following paragraphs present the results of the main engine subsystem data analysis, an example illustrating the development of peak period data bus traffic and computer processing loads by applying the data management design reference model to a portion of the main engine controller data output, and finally a graphical presentation of the peak period traffic and processing loads contributed by the propulsion systems of the shuttle stages.

1. Main Engine Subsystem Data Analysis

The results of the analysis of the main engine subsystem data rates are presented in Table IV-2, and are summarized in Table IV-3. As evidenced by the column headings of Table IV-2, these results include the specification of internal engine controller sample rates, engine controller to vehicle data bus transfer rates, resultant vehicle data bus traffic during start, steady-state, and shutdown intervals, in addition to notes pertaining to data usage.

2. Peak Traffic and Processing Load Development

The following example illustrates the application of the OCMS data management model to the regularly scheduled main engine controller-to-vehicle data bus data (see Table IV-2). The peak period vehicle data bus and computer processing estimates presented in Figures IV-10 through IV-15 were developed using the same techniques. The specific data selected for this example is the regularly scheduled data during steady-state main engine operation which has a total data rate (not traffic rate) of 4448 bits per second (BPS). By referring to our model we observe that the following rules apply to this case:

a) To obtain data from the engine controller, a data request containing one byte of address, one byte of function code, and one byte of parity is sent by the central computer to the engine controller. A data request, then, becomes

3 Bytes X 9 Bits/Byte = 27 Bits.

By multiplying the data request by its transfer rate the traffic due to a data request is calculated. The function code of the data request will specify a block of

data of the same transfer rate to be transmitted by the engine controller in its data response. The limitation on the size of a block of data that can be reported simultaneously is the format restriction on the maximum number of data bytes allowed.

b) Engine controller data responses contain one byte of address, up to 32 bytes of data, and one byte of parity. Engine controller words are defined to be 16 bits in length: 11 bits of data, 1 bit of sign, and 4 bits of identification. Vehicle data bus bytes are defined by the model to be 9 bits in length (8 bits of data plus 1 bit of parity); therefore, an engine controller word would occupy two vehicle data bus bytes. A maximum data response would be

34 Bytes X 9 Bits/Byte = 306 Bits.

Again, the traffic due to a data response is found by multiplying the number of response bits by the transfer rate.

The first step in the process, then, is to examine the data rate analysis for common rates. Table IV-2 reveals that during steady state engine operation there are 39 parameters which are regularly scheduled to be reported at a rate of 2 samples/second, and 10 parameters which are reported at a rate of 20 samples/second. Each of these parameters are 16 bits or 2 vehicle data bus bytes in length, hence 16 parameters of the same rate are blocked together to fill the 32 byte maximum data format. It follows that the traffic calculations are:

a) First 16 parameters at 2 samples/second.

Data request = 27 Bits X 2/second =	54 BPS	
Data response = 306 Bits X 2/second =	612 BPS	
	666 BPS	666 BPS

b) Second 16 parameters at 2 samples/second.

Same as a)	666 BPS

c) Remaining 7 parameters at 2 samples/second.

Data request = 27 Bits X 2/second = 54 BPS

Data response = 16 Bytes X 9 Bits/Byte X 2/second = 288 BPS

342 BPS 342 BPS

d) 10 parameters at 20 samples/second.

Data request = 27 Bits X 20/second = 540 BPS

Data response = 22 Bytes X 9 Bits/Byte X 20/second = 3960 BPS

4500 BPS 4500 BPS

TOTAL . . . . 6174 BPS

The preceding calculations demonstrate the application of the model system overhead to raw main engine controller data. The raw data rate of 4448 Bits/second, for regularly scheduled data from a single engine controller during steady state operation, translates to a vehicle data bus rate of 6174 bits/second. In the case of the booster, which has fourteen main engines, the total vehicle data bus traffic for this block of data would be 14 X 6174 BPS = 86.4 KBPS.

By proceeding in a similar fashion through the remainder of the main engine data, and that from other applicable subsystems, the peak vehicle data bus traffic and computer processing loads shown in Figures IV-10 through IV-15 were calculated. As indicated in these figures the traffic on the vehicle data bus system, due the propulsion system activity, peaks during main engine start. For the booster, that traffic peaks at approximately 430 KBPS, which corresponds to 43% of the vehicle date bus capacity. By the time liftoff occurs (approximately 2.5 seconds after the traffic peak) the main engines attain steady-state operation and the data bus traffic reduces to a steady-state level of 380 KBPS which is 38% of the vehicle data bus capacity. This is based on the reference booster for this study which baselines fourteen main engines. The results of the Phase B studies to date indicate a

requirement for only twelve main engines on the booster. With this configuration, the peak date traffic would reduce in essentially the same ratio as the reduction of main engines. That is, the peak traffic during main engine start would become 12/14 X 430 KBPS = 368.5 KBPS, or 36.8% of bus capacity, and the steady-state value during main engine burn would be 12/14 X 380 KBPS = 325 KBPS or 32.5% of bus capacity. After approximately three minutes of booster main engine operation, the propulsion generated data bus traffic reduces to a level of about 6 KBPS or 6% of capacity.

The peak central computer processing loads contributed by propulsion activities on the booster also occur during main engine start. That peak of 76% of CCC processing capability during main engine start reduces to a steady-state value of 62% by the time liftoff occurs. With the Phase B study baseline of twelve booster main engines, these values would reduce to about 65% at the peak and 53% during steady-state main engine operation. After main engine operation, the propulsion processing load reduces to a steady-state value of about 1% of CCC capacity.

For the orbiter, the peak in propulsion system generated data bus traffic occurs at main engine start where the peak value is 64 KBPS, or 6.4% of capacity. The corresponding peak in computer processing load is 11.5% of capacity. During steady-state main engine operation, these values become 57.2 KBPS (5.7% of bus capacity) and 9.4% of computer processing capacity. After the three minute main engine operation interval, the orbiter data bus traffic and processing loads due to propulsion activity reduce to steady-state values of about 3 KBPS and 0.5% respectively.

TABLE IV-2

MAIN ENGINE SUBSYSTEM DATA RATE ANALYSIS

Parameter	Internal Eng. Controller Sample Rate	Start Transient Eng/Vehicle Transfer Rate	Start Transient Bits/Sec.	Steady State Eng/Vehicle Transfer Rate	Steady State Bits/Sec.	Shutdown Eng/Vehicle Transfer Rate	Shutdown Bits/Sec.	Notes
FUEL PRESS., F.P.B. INLET	100/SEC	20/SEC	320	2/SEC	32	20/SEC	320	M.R.
FUEL TEMP., F.P.B. INLET	20/SEC	-	-	2/SEC	32	-	-	M.R.
FLOW-OXID. TO PREBURNERS	100/SEC	-	-	2/SEC	32	-	-	"
FLOW-OXID. TO MAIN C.C.	100/SEC	-	-	2/SEC	32	-	-	"
PRESS., OXID., PREB. FLOWMETER	100/SEC	20/SEC	320	2/SEC	32	20/SEC	320	"
TEMP., OXID., PREB. OXID. FLOW	20/SEC	-	-	2/SEC	32	-	-	"
PRESS., OXID., MAIN C.C. FLOW	100/SEC	20/SEC	320	2/SEC	32	20/SEC	320	"
TEMP., OXID., MAIN C.C. FLOW	20/SEC	-	-	2/SEC	32	-	-	"
PRESS., FUEL, O.P.B. INLET	100/SEC	-	-	2/SEC	32	-	-	"
ΔP, OPB, FUEL INLET TO CHAMBER	100/SEC	-	-	2/SEC	32	-	-	"
ΔP, F.P.B, FUEL INLET TO CHAMBER	100/SEC	-	-	2/SEC	32	-	-	"
PRESS., MAIN COMB. CHAMBER	100/SEC	20/SEC	320	20/SEC	320	20/SEC	320	Thrust
PRESS., FUEL, INLET TO LPFTPA	20/SEC	20/SEC	320	20/SEC	320	-	-	Start Monitor; POGO Monitor
PRESS., OXID., INLET TO LPOTPA	20/SEC	20/SEC	320	20/SEC	320	-	-	" " " "
PRESS., FUEL, LPFTPA DISCH.	20/SEC	20/SEC	320	2/SEC	32	-	-	Start Monitor
PRESS., OXID., LPOTPA DISCH.	20/SEC	20/SEC	320	2/SEC	32	-	-	Start Analysis
RPM, LPFTPA	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	" "
RPM, HPFTPA	20/SEC	20/SEC	320	2/SEC	32	10/SEC	160	" "
RPM, LPOTPA	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	" "
RPM, HPOTPA	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	" "
TEMP., LPOTPA INLET	20/SEC	2/SEC	32	-	-	-	-	" "
TEMP., LPFTPA INLET	20/SEC	2/SEC	32	-	-	-	-	" "
ΔP, FUEL COOLANT TO HOT GAS M.	20/SEC	2/SEC	32	2/SEC	32	-	-	Flt. Safety; Trend
VACUUM JACKET PRESS., (1)	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	Start Monitor
VACUUM JACKET PRESS., (2)	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	" "
VACUUM JACKET PRESS., (3)	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	" "
VACUUM JACKET PRESS., (4)	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	" "
PRESS, FUEL, LPFTPA TURB. INL.	20/SEC	20/SEC	320	-	-	-	-	" "
PRESS., OXID. HEAT EXCH. OUTLET	20/SEC	10/SEC	160	2/SEC	32	10/SEC	160	Autogenous Syst.
PRESS., FUEL, NOZZLE COOL. OUTLET	20/SEC	10/SEC	160	2/SEC	32	10/SEC	160	" "
PRESS., MAIN TCA FUEL PURGE CK. V. i	20/SEC	2/SEC	32	2/SEC	32	20/SEC	320	Trend; Control
PRESS., MAIN TCA OXID. PURGE CK. V. i	20/SEC	2/SEC	32	2/SEC	32	20/SEC	320	" "
PRESS., HPOTPA SEAL CAVITY	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	Flight Safety
PURGE SUPPLY PRESSURE	20/SEC	2/SEC	32	2/SEC	32	2/SEC	32	Start Monitor
PRESS., OXID. PREB. CHAMBER	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	Start Analysis

TABLE IV-2 (Continued)

MAIN ENGINE SUBSYSTEM DATA RATE ANALYSIS

Parameter	Internal Eng. Controller Sample Rate	Start Transient		Steady State		Shutdown		
		Eng/Vehicle Transfer Rate	Bits/Sec.	Eng/Vehicle Transfer Rate	Bits/Sec	Eng/Vehicle Transfer Rate	Bits/Sec.	
PRESS., FUEL PREB. CHAMBER	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	Start Analysis
PRESSURE, HPOTPA THRUST BAL.	100/SEC	-	-	2/SEC	32	-	-	Flt. Safety
PRESSURE, PREB. PURGE SOL. V. OUT.	20/SEC	2/SEC	32	2/SEC	32	20/SEC	320	Trend; Maint.
CALC. M.R.	20/SEC	-	-	20/SEC	320	-	-	Perf. Check
CALC. THRUST	20/SEC	-	-	20/SEC	320	-	-	" "
M.R. ERROR	20/SEC	-	-	20/SEC	320	-	-	" "
THRUST ERROR	20/SEC	-	-	20/SEC	320	-	-	" "
LPFTPA VIBRATION	100/SEC	-	-	2/SEC	32	-	-	Trend; Malf. Ident
HPFTPA VIBRATION	100/SEC	-	-	2/SEC	32	-	-	" " "
LPOTPA VIBRATION	100/SEC	-	-	2/SEC	32	-	-	" " " ; Flt. Saf.
HPOTPA VIBRATION	100/SEC	-	-	2/SEC	32	-	-	" " " " "
TEMP., FPB CHAMBER	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	" " "
TEMP., OPB CHAMBER	20/SEC	20/SEC	320	2/SEC	32	20/SEC	320	" " "
IGN. CURRENT, OPB	20/SEC	One - 16 Bit Word		-	-	-	-	Control; Trend
IGN. CURRENT, FPB	20/SEC	One - 16 Bit Word		-	-	-	-	" "
IGN. CURRENT, M.C.C.	20/SEC	One - 16 Bit Word		-	-	-	-	" "
POSITION, FUEL MAIN VALVE	100/SEC	50/SEC	800	-	-	50/SEC	800	" "
POSITION, OXID. MAIN VALVE	20/SEC	20/SEC	320	-	-	20/SEC	320	" "
POSITION, OPB OXID. CONT. VALVE	100/SEC	20/SEC	320	20/SEC	320	20/SEC	320	" "
POSITION, OPB FUEL CONT. VALVE	100/SEC	20/SEC	320	20/SEC	320	20/SEC	320	" "
POSITION, FPB OXID. CONT. VALVE	100/SEC	20/SEC	320	20/SEC	320	20/SEC	320	" "
POSITION, FUEL RECIRC. SEL. VALVE	20/SEC	20/SEC	320	-	-	20/SEC	320	" "
POSITION, OXID. RECIRC. SEL. VALVE	20/SEC	20/SEC	320	-	-	20/SEC	320	" "
POSITION, FUEL RECIRC. CONT. VALVE	20/SEC	20/SEC	320	-	-	20/SEC	320	" "
IGNITION DETECTOR, OPB	DISCRETE	One - 6 Bit Word		-	-	-	-	Control, Safety
IGNITION DETECTOR, FPB	DISCRETE	One - 6 Bit Word		-	-	-	-	" "
IGNITION DETECTOR, MCC	DISCRETE	One - 6 Bit Word		-	-	-	-	" "
POSITION, EXT. NOZZLE	20/SEC	-	-	2/SEC	32	-	-	Trend
POSITION, FUEL MAIN VALVE	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		Control
POSITION, OXID. MAIN VALVE	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		"
POSITION, OPB FUEL CONT. VALVE	DISCRETE	One - 6 Bit Word		-	-	-	-	"
POSITION, OPB OXID. CONT. VALVE	DISCRETE	Two - 6 Bit Words		-	-	-	-	"
POSITION, FPB OXID. CONT. VALVE	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		"
POSITION, OXID. RECIRC. SEL. V.	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		"
POSITION, FUEL RECIRC. SEL. V.	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		"

TABLE IV-2 (Continued)

MAIN ENGINE SUBSYSTEM DATA RATE ANALYSIS

Parameter	Internal Eng. Controller Sample Rate	Start Transient Eng/Vehicle Transfer Rate	Start Transient Bits/Sec.	Steady State Eng/Vehicle Transfer Rate	Steady State Bits/Sec.	Shutdown Eng/Vehicle Transfer Rate	Shutdown Bits/Sec.	Notes
POSITION, FUEL RECIRC. CONT. V.	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		Control
POSITION, OPB IGN. OX. VALVE	DISCRETE	Four - 6 Bit Words		-	-	-	-	Control
POSITION, FPB IGN. OX. VALVE	DISCRETE	Four - 6 Bit Words		-	-	-	-	"
POSITION, MCC IGN. OX. VALVE	DISCRETE	Four - 6 Bit Words		-	-	-	-	"
TIME, OPBIGN. OXID. VALVE	DISCRETE	Two - 16 Bit Words		-	-	-	-	Trend
TIME, FPB IGN. OXID. VALVE	DISCRETE	Two - 16 Bit Words		-	-	-	-	Trend
TIME, MCC IGN. OXID. VALVE	DISCRETE	Two - 16 Bit Words		-	-	-	-	Trend
POSITION, PREB. OX. PURGE SOL. V.	DISCRETE	Two - 16 Bit Words		-	-	Two - 6 Bit Words		Control
TIME, PREB. OX. PURGE SOL. V.	DISCRETE	One - 16 Bit Word		-	-	One - 16 Bit Word		Trend
POSITION, MAIN TCA OX. PURGE SOL. V.	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		Control
TIME, MAIN TCA OX. PURGE SOL. V	DISCRETE	One - 16 Bit Word		-	-	One - 16 Bit Word		Trend
POSITION, MAIN TCA FUEL PURGE SOL. V.	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		Control
TIME, MAIN TCA FUEL PURGE SOL. V.	DISCRETE	One - 16 Bit Word		-	-	One - 16 Bit Word		Trend
POSITION, EXT. NOZ. COOL. SOL. VALVE	DISCRETE	Two - 6 Bit Words		-	-	Two - 6 Bit Words		ORBITER only; Trend; Control
TIME, EXT. NOZ. COOL. SOL. VALVE	DISCRETE	One - 16 Bit Word		-	-	One - 16 Bit Word		" " " "
POSITION, EXT. NOZ. A TRACK	DISCRETE	-	-	Two - 6 Bit Words		-	-	" " Control
POSITION, EXT. NOZ. B TRACK	DISCRETE	-	-	Two - 6 Bit Words		-	-	" " "
POSITION, EXT. NOZ. C TRACK	DISCRETE	-	-	Two - 6 Bit Words		-	-	" " "
EXT. NOZZLE LOCK - A	DISCRETE	-	-	One - 6 Bit Word		-	-	" " "
EXT. NOZZLE LOCK - B	DISCRETE	-	-	One - 6 Bit Word		-	-	" " "
EXT. NOZZLE LOCK - C	DISCRETE	-	-	One - 6 Bit Word		-	-	" " "
FLOW FPB OX. PURGE	DISCRETE	-	-	-	-	Two - 6 Bit Words		Analysis; Trend
FLOW OPB OX. PURGE	DISCRETE	-	-	-	-	Two - 6 Bit Words		" "
SUB-TOTAL DATA			9184		4448		8192	
STATUS WORD (2)	20/SEC	20/SEC	640	20/SEC	640	20/SEC	640	Controller/C.C.C.
INTERFACE BITE	20/SEC	20/SEC	120	20/SEC	120	20/SEC	120	Checks
CONTROL COMMAND VERIF. (4)	20/SEC	20/SEC	640	20/SEC	640	20/SEC	640	
SUB-TOTAL DATA			1400		1400		1400	
TOTAL - ALL			10,584		5848		9592	
ONE TRANSFER DISCRETES			416		54 Bits		208	
HYDRAULICS, GIMB. (ESTIM)			640		3000		640	

TABLE IV-3

MAIN ENGINE SUBSYSTEM
DATA RATE SUMMARY

(MAIN ENGINE CONTROLLER TO VEHICLE DATA BUS)

TYPE OF TRAFFIC	START	STEADY STATE	SHUTDOWN
All data from non-discrete devices	9,184 B/Sec.	4,448 B/Sec.	8,192 B/Sec.
Interface test, status, verifications	1,400 B/Sec.	1,400 B/Sec.	1,400 B/Sec.
TOTAL	10,584 B/Sec.	5,848 B/Sec.	9,592 B/Sec.
One-time transfer of discretes	416 Bits	54 Bits	208 Bits
Hydraulic system gimbal actuator data rates.	640 B/Sec.	3,000 B/Sec.	640 B/Sec.

NOTE: All non-discrete data words are assumed to be 16 bit length.

This page not used.

PEAK DATA CONSTITUENT TIMELINES
BOOSTER MAIN ENGINE START

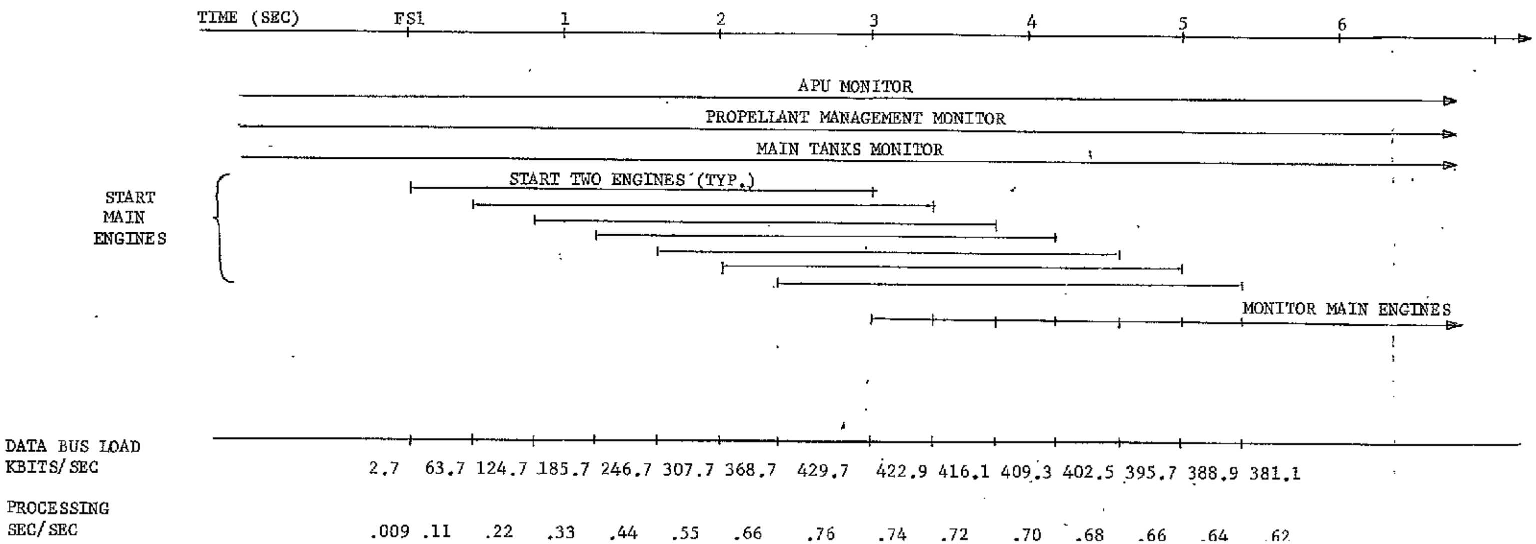


FIGURE IV-10

PEAK DATA COMPOSITE TIMELINE
BOOSTER MAIN ENGINE START

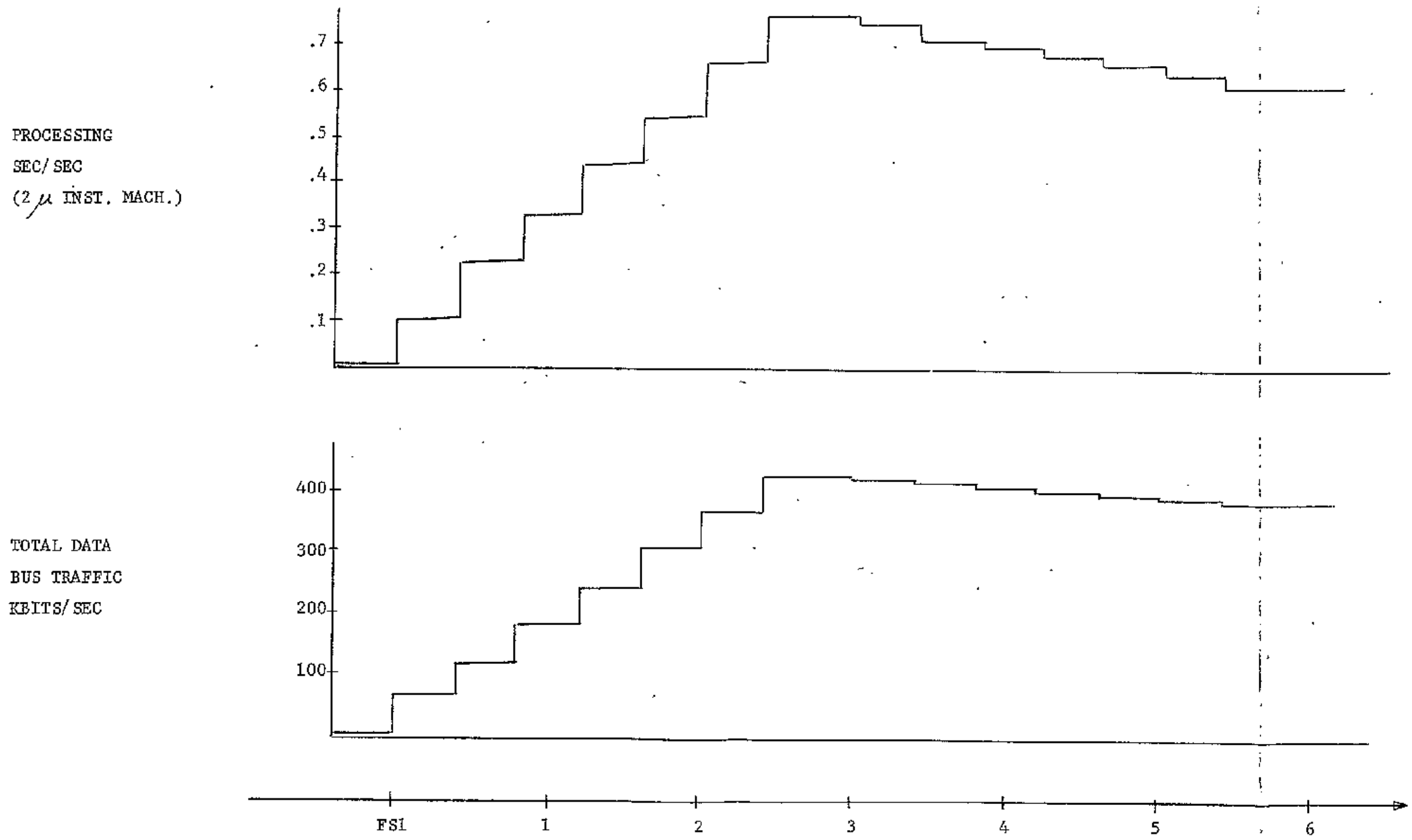


FIGURE IV-11

FOLDOUT FRAME 1

FOLDOUT FRAME 2

PEAK DATA CONSTITUENT TIMELINES

BOOSTER MAIN ENGINE SHUTDOWN AND SEPARATION

IV-45 & IV-46

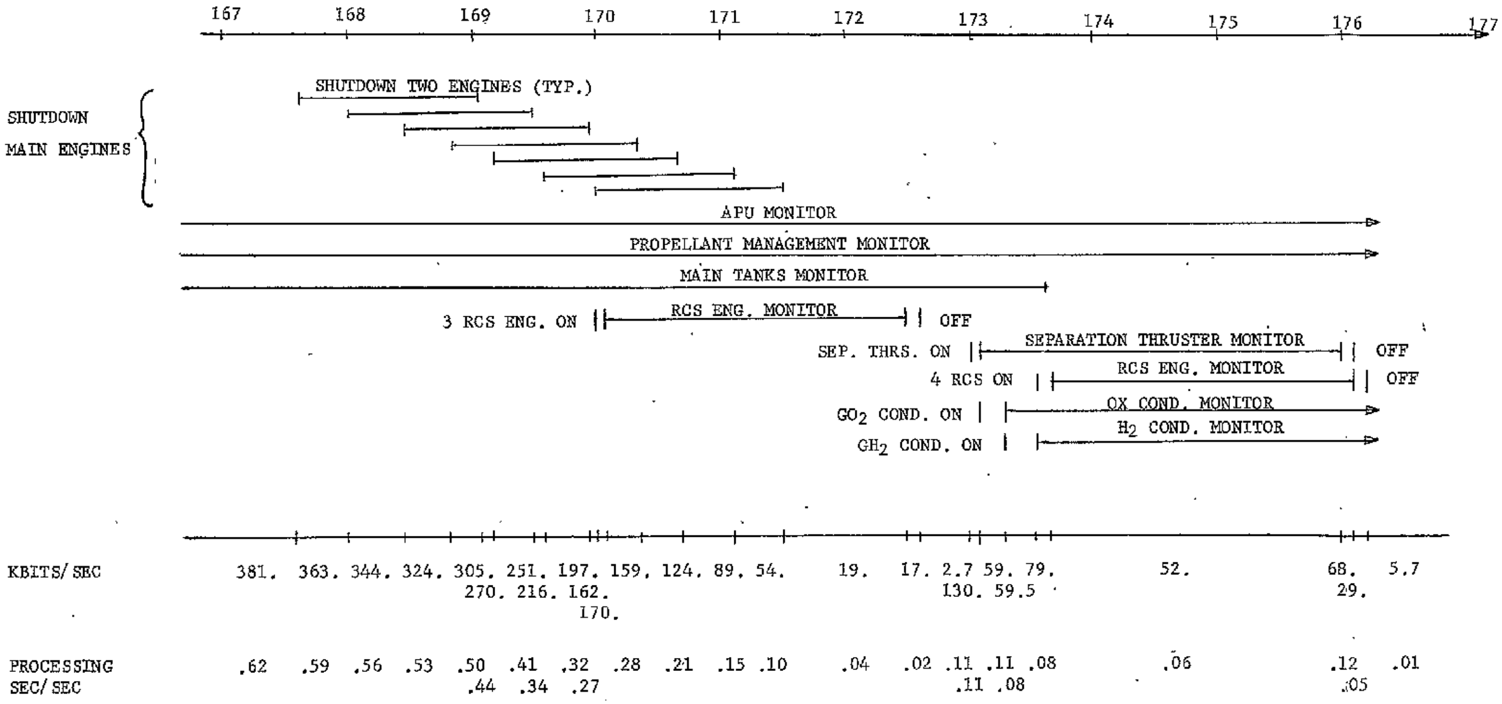


FIGURE IV-12

PEAK DATA COMPOSITE TIMELINE

BOOSTER MAIN ENGINE SHUTDOWN AND SEPARATION

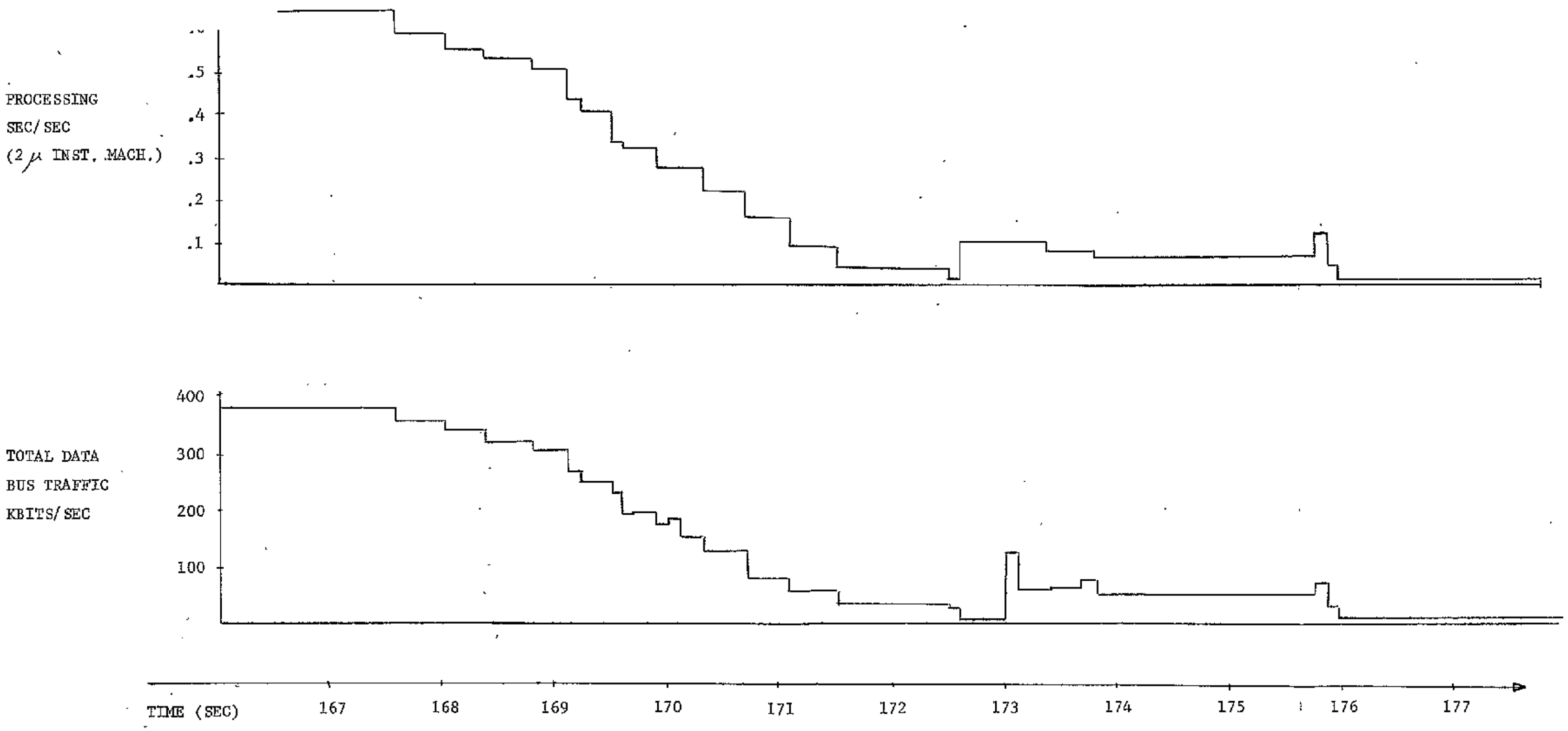


FIGURE IV-13

PEAK DATA CONSTITUENT TIMELINES
ORBITER MAIN ENGINE OPERATION

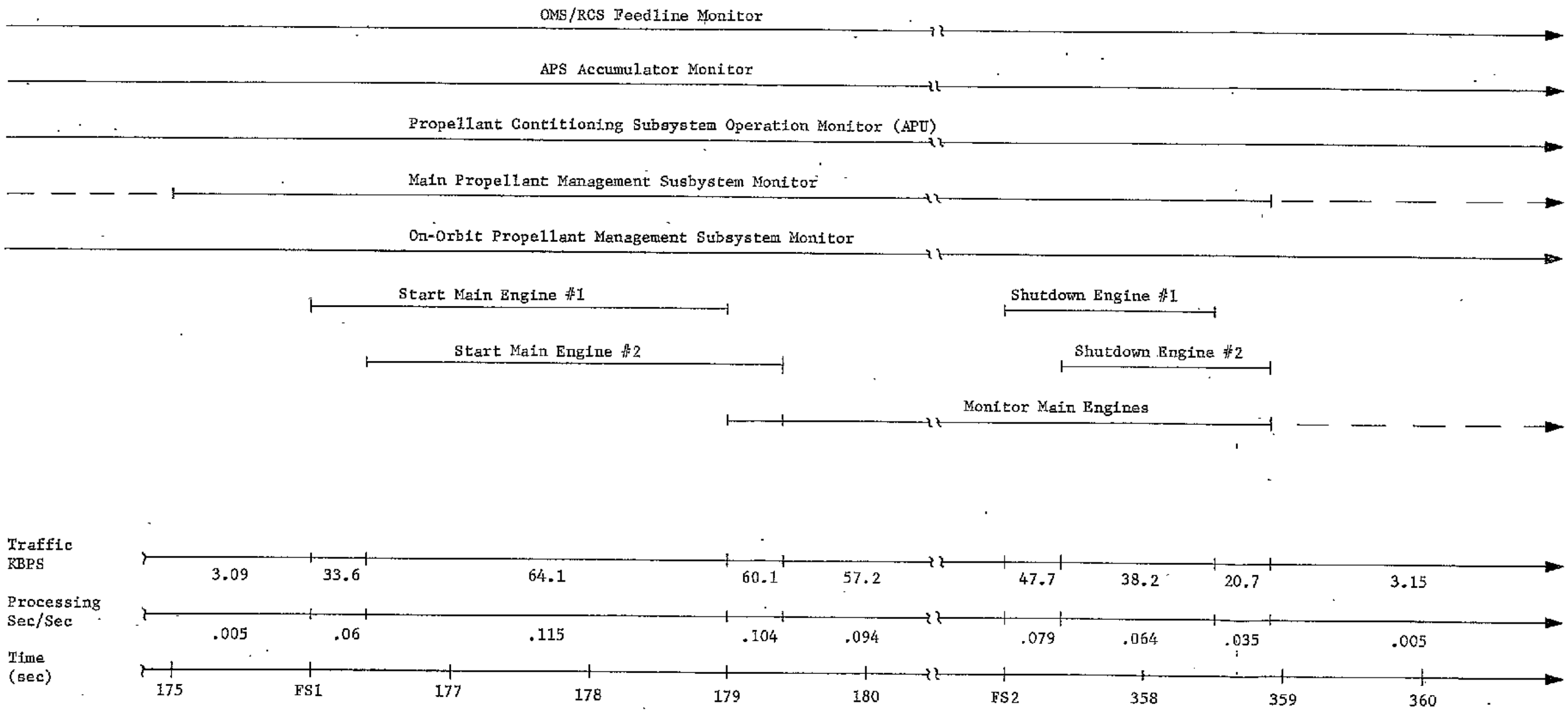


FIGURE IV-14

PEAK DATA COMPOSITE TIMELINE
ORBITER MAIN ENGINE OPERATION

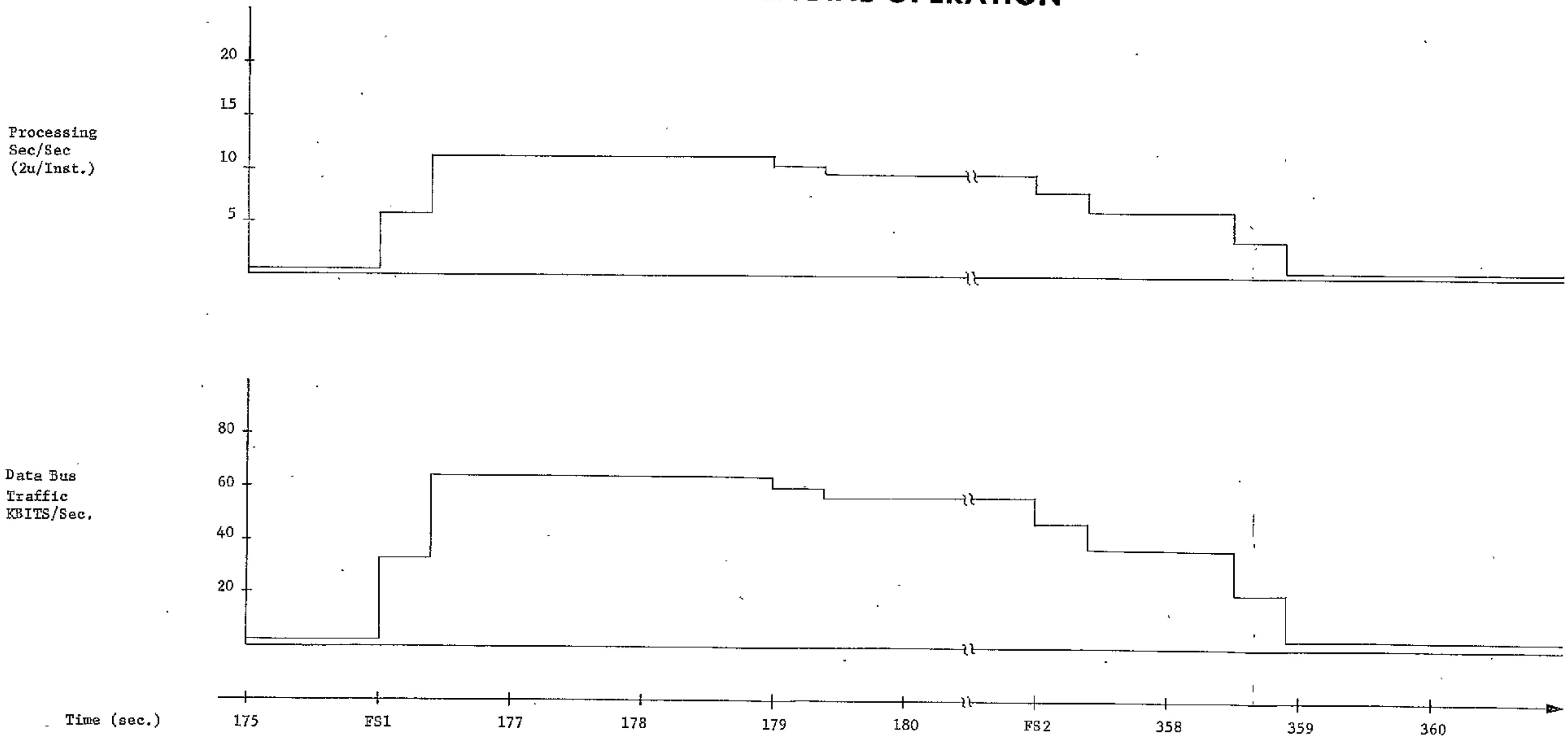


FIGURE IV-15

C. DISPLAYS AND RECORDING

The electronics design reference model, presented in Volume II, assumes that adequate display capability and a maintenance recording capability will be provided as a part of the vehicle electronics systems, to support all of the vehicle systems requirements for display and recording. The application of these capabilities to the propulsion systems checkout and monitoring functions is discussed in paragraphs that follow:

1. Display

The general guideline for assigning information for onboard display is that only information necessary for crew evaluation or action will be displayed. Since most routine control, reconfiguration of redundant systems, and emergency responses are provided automatically, display requirements for these purposes are very low. Onboard checkout, inflight monitoring, and emergency detection functions have always existed in manned aircraft and spacecraft systems, but they have been performed primarily by the crew, aided by ground personnel. These functions account for a large proportion of the information presently displayed on such vehicles. With automation of these functions, their display requirements are reduced accordingly to only that information necessary for the crew to be aware of any need for crew action, for making decisions regarding optional actions, and for carrying out procedures associated with a selected action. To avoid display clutter, i.e., display of more information at one time than the crew can read and readily understand, the more detailed and less urgent information should be displayed on a call-up basis.

Applying the above considerations, the types of information to be displayed for the propulsion systems reduce to the following:

a. Operator or crew instructions, such as procedure steps for manual operations or checkoffs, both ground and flight.

b. System status, such as operating modes and redundancy levels.

c. Propellant quantities and consumption rates.

d. Malfunction detection or prediction notification and identification, during ground operations when personnel are onboard and inflight when corrective action by the crew is possible.

e. Caution and warning indications

f. Postflight printouts of maintenance data.

Adequate display provisions for all of the above, with the exception of printout capability, are assumed in the electronics design reference model. Printout capability is recommended as a part of ground control and display provisions. Since the information to be displayed (other than that used solely for ground operation) is used primary to enable the crew to take precautionary or corrective action necessary to their safety, redundant displays are recommended for all of the above listed information except the postflight printout of maintenance data.

2. <u>Recording</u>

Data recording capability is required for performance data, fault identification results, and operating history records, in accordance with the OCMS criteria presented in Section A of this chapter. To further expand on approaches to inflight recording capability and the utilization of the resultant recordings, some applications from current aircraft practices are briefly described in the following paragraphs.

The AIDS system, currently flying in line commercial operations aboard three KLM DC-9-30 aircraft on a trial basis, employs a maintenance and performance recorder to monitor up to 400 aircraft parameters. In this system, the data recording rate is varied as a function of the flight mode and data compression is achieved by computer processing prior to recording. This compression is accomplished by redundancy reduction techniques employing various forms of limit checking. Postflight, the data is converted to be compatible with ground computer tape reader input format. Ground processing is then used to convert the data to engineering units, check it by statistical techniques, and produce parameter plots and lists for analysis. The reduced data is used to compare performance with other fleet systems to make relative assessments and highlight fleet trends. It is also used for flight profile analyses to assist flight crews, improve training procedures, and optimize fuel management (by comparison of same type engines and appropriate adjustments).

The C-5A MADAR system employs a maintenance data recorder to record digital information regarding trend and LRU failure data, in a format compatible with ground processing equipment. Continuous data is not recorded. Instead, a computer tests the

parameter values to determine if they have changed more than a preprogrammed allowable deviation since their last recorded value. Values within allowable deviations are not recorded. If a value exceeds its allowable deviation, the test point number and a time reference is supplied to the recorder. This technique is the same as one form of limit checking used in the AIDS system described above.

Automatic engine maintenance recording is being employed by UAL on Boeing 737 aircraft, utilizing a flight-borne recorder. Three complete sets of engine data are recorded per flight; at take-off, climb, and cruise. A ground computer normalizes the recorded data and compares it with idealized performance data for a standard engine. Deviations from standard are then used to establish a trend for each parameter. When an engine's individual parameter trends change from their own previous levels by more than prescribed amounts, a warning is printed. Monthly summaries of individual engines and fleet averages are printed out for analysis of fleet trends.

The application of the Space Shuttle onboard maintenance recording provisions to the propulsion systems checkout and monitoring functions is discussed in the following paragraphs.

a. Recording Rates - The peak propulsion systems data traffic on the vehicle data bus has been estimated as 430 kbps for the booster and 64 kbps for the orbiter. Only a portion of this is parameter data, however. The majority of the data bus traffic is accounted for by commands, engine controller status signals, and the data traffic necessary to operate the data bus and check for errors. The actual peak parameter data is approximately 140 kbps for the booster and 35 kbps for the orbiter. Each main engine accounts for approximately 9.2 kbps of this data. These peak values are sustained during main engine start. They then drop off to 77 kbps for the booster and 26 kbps for the orbiter during the remainder of the time the main engines are running. Each main engine, running at steady state, accounts for approximately 4.4 kbps of this data. If all of these data are recorded, the recording rates during peak activity will exceed what was assumed in the DRM to be a reasonable allocation of recording (75 kbps for the booster propulsion systems and 15 kbps for the orbiter propulsion systems). Further, they do not include any recorder overhead for tagging of data and error coding

b. Reduction of Recording Rates - The data rates presented above have taken into account the use of a number of techniques

to reduce the quantity of data. These included: data averaging techniques in the engine controllers, acquisition of data only during periods of expected activity, and parameter extraction (transformation of signals to abbreviated forms) by signal conditioners.

Data compression techniques were examined as a means of achieving further reduction in the amount of data without reducing the information content. However, assuming even a reasonably simple compression technique (redundancy reduction by zero-order predictor), it was found that computer processing loads would increase by at least 40% if data compression were accomplished by onboard computer processing. This estimate assumed a compression ratio of 5:1 before tagging of data.

Compressed data requires a buffer between the computer and recorder to transform the sporadic emergence of non-redundant samples to a steady flow for efficient recording. Although the data then is recorded at a steady rate over periods of time, the parameters represented by the data are in random order and, therefore, must be suitably tagged for identification. Also, because they are delayed by the buffer, they must be tagged with a time-of-measurement. Such tagging often cuts the effective compression ratio in half and sometime results in a negative compression ratio, depending on the activity of the data. Further, the variance in individual runs of deleted samples can produce overflow and emptying of the buffer unless the buffer is oversized, estimates of average compression ratios are very good, and/or adaptive compression techniques are used. Obviously, the characteristics of the input data must be well known for redundancy reduction techniques to be designed for a system.

The conclusion reached from this analysis was that the compression of data before recording would not only require an extensive buffer between the computer and recorder, but also would either overload the computer during peak processing times or would require considerable additional data storage capability to temporarily hold data until it could be processed for compression in non-real time. There is, of course, the possibility of adding another computer, dedicated to data compression. A better approach would be to use the mass memory of the vehicle central computer complex to temporarily hold uncompressed data (suitably tagged to identify time and parameter) during peak data periods and transfer it to the recorder during periods of lower activity.

The very best means of reducing data quantity is to carefully study each subsystem with later performance analysis in mind, to determine exactly what data is needed for that analysis and what quality standard it must meet to convey the really necessary parameter information.

c. Recorder Capabilities - A number of existing and in-development flight-borne tape recorders were investigated to determine the reasonableness of the DRM assumptions on recording rates. Findings of this investigation were as follows:

1) The Apollo CSM recorder capability is 1.6 kbps for 120 minutes, or 51.2 kbps for proportionately shorter times.

2) The Skylab Airlock Module Recorder capability is 5.12 kbps for 240 minutes.

3) The Apollo Telescope Mount Auxiliary Storage and Playback Unit capability is 4 kbps of recording for 90 minutes, with PCM playback in 5 minutes at 72 kbps.

4) The Skylab Earth Resources Experiment tape recorder (Ampex AR 700) is a 28 track recorder capable of recording at 1 Mbps per channel for 15 minutes, and for proportionately longer times at lower bit rates.

If the use of the Earth Resources Experiment recorder is considered, the DRM assumptions on recording capability are conservative by sizable factors. The total quantity of data that can be handled by the data bus could obviously be handled by this recorder.

d. Selected Approach - The selected approach to inflight data recording is to require the vehicle maintenance recorder to provide sufficient recording capacity, both data rate and recording time, to store the required propulsion systems data, uncompressed, in suitable format and suitably identified as to time and parameter to allow efficient post-flight processing for reduction and evaluation.

D. GROUND SUPPORT EQUIPMENT FOR CHECKOUT AND MONITORING

The propulsion checkout and monitoring requirements are satisfied by the use of onboard systems except in a very limited number of cases where considerations such as cost, weight, technology limitations, personnel safety, and overall system effectiveness has led to the recommendation of ground support equipment (GSE) for checkout and monitoring. The recommended items of GSE for checkout and monitoring and their applications are presented in Table IV-4. The type and function of this GSE (as defined in the application column) make readily apparent the reasons for these recommendations. This GSE was identified from an analysis of the ground operations defined by the Checkout and Monitoring Requirements Analysis, the LRU Maintenance Procedures, and the FMEAs, as well as an overall systems analysis.

The vast majority of GSE items identified in the LRU Maintenance Procedures and the FMEAs is not specifically associated with checkout and monitoring. Their functions are handling, refurbishment, and servicing. Matrices of this general GSE and its usage are shown in Table IV-5 . Applicability of a particular GSE item to a given propulsion element is indicated by an (X) in the appropriate location.

The CCC will be used during the post landing phase to process flight data to generate maintenance action printouts in addition to performing trend analysis and editing performance data for use by subsystem analysts. This data reduction process will be accomplished by loading ground software routines into the CCC during the post-landing cooldown period. The remaining activity for the CCC during the post landing phase is the executive control of the safing and purging operations. The total computer time for the post landing phase is estimated to be six hours.

During the maintenance phase, the principal uses of the CCC will be retest of replaced LRUs and subsystem reverification. While detailed fault isolation routines may at times be required, it is anticipated that this activity will be very minimal and may be neglected in estimating ground operating time for the CCC. While the number of power-on/power-off cycles on the CCC will undoubtedly vary from mission to mission, it is estimated that the CCC will be in use not more than two hours for each of the nine 8-hour shifts during the maintenance cycle, or a total of not more than eighteen hours.

During the prelaunch phase, the CCC is used to conduct integrated preflight checkout for the vehicle systems and subsystems. The maximum time estimated for vehicle subsystem, system, and post-mate checks is thirty-six hours.

The CCC is used during the launch phase to be in executive control of the launch complex facilities during servicing operations and to perform final system checks. The total time estimated for these activities is fourteen hours.

The total time of operation for the CCC during the turnaround cycle for an operational shuttle, then, is a maximum of seventy-four hours.

TABLE IV - 4

GSE FOR CHECKOUT AND MONITORING

ITEM	APPLICATION
Leak Test Equipment	Used for test of fluid line connections after LRU replacement. Required only if onboard leak detection system does not provide sufficient accuracy for this function.
Optical Test Equipment	For turbofan engine damage inspection and for ignition spark plug inspection.
Vacuum Test Equipment	For vacuum check of replaced vacuum-jacketed propellant lines.
Data Processing System	For generation of computer program source tapes, conversion of digital data tapes to graphical output, and for reduction of data tapes to statistical data for trend and performance analysis.
Oil Sampling and Contamination Analysis Equipment	For contaminate and particulate analysis of lubricants and hydraulic fluids.
Electronic Simulation Equipment	To perform fault isolation primarily in the LRU-SENSOR-DIU chain to a level not readily accomplished by onboard equipment, such as certain identification of an open circuit location.
Remote Control and Display Panel	To operate OCMS during maintenance operations to preclude crew compartment congestion and during propellant loading and purge operations for personnel safety.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE IV-5

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

A. MAIN PROPULSION SYSTEM

REQUIRED GSE

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Equip.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal&Duct Supporting Fixture	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand.Eqmt.	Fuel Preburner Hand. Eqmt.	Ox. Preburner Hand. Eqmt.	Propellant Line Hand. Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv. & Press.Meas.Eqmt.	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.
1-B/0	MPMS	LO2 Tank Vent Pkg.	X	X	X	X	X																						X						
12-B/0	MPMS	LH2 Tank Vent Pkg.	X	X	X	X																													
2-B/0	MPMS	LO2 Tank Isol. Valve	X		X	X	X		X																				X						
3-B/0	MPMS	LH2 Tank Isol. Valve	X		X	X	X		X																				X						
4-B	MPMS	LO2 Prevalve	X	X	X	X	X																						X						
5/20-B/0	MPMS	LH2 Fill Valve	X	X	X	X	X																						X						
18/15-B/0	MPMS	LO2 Fill Valve	X	X	X	X	X																						X						
6/25-B/0	MPS	Fuel Autog. Filter					X																						X						
7/22-B/0	MPS	Ox. Autog. Filter					X																						X						
8/26-B/0	MPS	Fuel Press. Cont. Valve	X				X						X																X						
9/23-B/0	MPS	Ox. Press. Cont. Valve	X				X						X																X						
10/24-B/0	MPS	Ox. Press. Cont. Orifice					X																						X						
11/27-B/0	MPS	Fuel Press. Cont. Orifice					X																						X						
13/19-B/0	MPMS	Fuel Fill Coupling					X																						X						
16-0	MPMS	Ox. Fill Coupling					X																						X						
14-B/0	MPMS	Fuel Tank Vent Coup.					X																						X						
15/21-B/0	MPS	Fuel Tank Prepress. Coup.					X																						X						
17/13-B/0	MPS	LO2 Tank Prepress. Coup.					X																						X						
16/17-B/0	MPMS	LO2 Recirc. Coup.					X																						X						
18-B/0	MPMS	LH2 Recirc. Coup.					X																						X						
19-B	MPMS	LO2 Fill Coup.					X																						X						
20-B	MES	Main Engine	X		X	X	X		X	X	X	X																	X						
4-0	OPRO	On-Orb. LO2 Vent Pkg.					X						X																X						
5-0	OPRO	On-Orb. LH2 Vent Pkg.					X						X																X						
6-0	OPRE	On-Orb. Fuel Tank Press. Filt.					X																						X						
9-0	OPRE	On-Orb. LO2 Tank Press. Filt.					X																						X						

LEGEND: B=Booster, O=Orbiter; MPMS=Main Propellant Management Subsystem; MPS=Main Pressurization Subsystem; OPRO=On-Orbit Propellant Management Subsystem; OPRE=On-Orbit Pressurization Subsystem

TABLE IV-5 (Cont.)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

A. MAIN PROPULSION SYSTEM

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixture	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand.Eqmt.	Fuel Preburner Hand. Eqmt.	Ox. Preburner Hand. Eqmt.	Propellant Line Hand. Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv. & Press.Meas.Eqmt.	Torque Meas. Device	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.
7-0	OPRE	On-Orb. Fuel Tank Press. Reg.					X						X																X							
10-0	OPRE	On-Orb. LO2 Tank Press. Reg.					X						X																X							
8-0	OPRE	Fuel Tank Press. Shutoff Valve					X						X																X							
11-0	OPRE	Ox. Tank Press. Shutoff Valve					X						X																X							
28-0	MES	Main Engine	X		X	X	X		X	X	X	X																	X							
1-B/O	MES	Low Press. Turbopump	X			X	X								X														X	X						
2-B/O	MES	High Press. Turbopump	X			X	X									X													X							
3-B/O	MES	Low Press. Turbopump	X		X	X	X				X						X												X	X						
4-B/O	MES	High Press. Turbopump	X			X	X											X											X							
5-B/O	MES	Fuel Preburner	X			X	X												X										X							
6-B/O	MES	Oxidizer Preburner	X			X	X													X									X							
7-B/O	MES	Fuel Main Valve					X																						X							
8-B/O	MES	Ox. Main Valve	X		X	X	X																						X							
9-B/O	MES	Fuel Control Valve					X																						X							
10-B/O	MES	Ox. Control Valve			X	X	X																						X							
11-B/O	MES	Ox. Control Valve			X	X	X																						X							
12-B/O	MES	Propellant Lines				X	X															X							X							
13-B/O	MES	Interconnect Lines	X			X	X				X												X						X							
14-B/O	MES	Select Valve	X			X	X																						X							
15-B/O	MES	Select Valve	X			X	X																						X							
16-B/O	MES	Control Valve	X			X	X																						X							

LEGEND: B=Booster O=Orbiter OPRE=On-Orbit Pressurization Subsystem MES=Main Engine Subsystem

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE IV-5 (Cont.)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

A. MAIN PROPULSION SYSTEM

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixt.	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand. Eqmt	Fuel Preburner Handling Eqmt.	Ox. Preburner Handling Eqmt.	Propellant Line Handling Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv.& Press.Meas.Eqmt.	Torque Meas. Device	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.
17-B/0	MES	Recirc. Regulator	X			X	X																						X							
18-B	MES	Booster Nozzle	X				X			X	X													X					X							
19-B/0	MES	Coolant Control Valve				X	X																						X							
20-B/0	MES	Interconnect Lines	X			X	X																						X							
21-B/0	MES	TCA Igniters					X				X																		X							
22-B/0	MES	Interconnect Lines					X																						X							
23-B/0	MES	Gimbal Actuators	X			X	X																		X	X			X							
24-B/0	MES	Engine Controller																									X									
25-B/0	MES	Wire Harness																																		
26-B/0	MES	Instrumentation Harness																																		
27-B/0	MES	Check Valve				X	X																						X							
28-B/0	MES	Check Valve			X	X	X																						X							
29-B/0	MES	Heat Exchanger				X	X																						X							
30-B/0	MES	Purge Valves				X	X																						X							
31-0	MES	Extendible Nozzle																										X								
32-0	MES	Nozzle Deployment Kit																						X												

REQUIRED GSE

LEGEND: B = Booster; 0 = Orbiter; MES = Main Engine Subsystem

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE IV-5 (Cont'd)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

B. AUXILIARY PROPULSION SYSTEM

LRU NUMBER	LRU SUBS.	LRU DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixture	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand.Eqmt.	Fuel Preburner Handling Eqmt.	Ox. Preburner Handling Eqmt.	Propellant Line Handling Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv.& Press.Meas.Eqmt.	Torque Meas. Device	Engine Removal Fixt.	Turbopump Removal Fixt.	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.
1-B	RCS	Engine Package					X					X																	X		X					
1-B	SEP	Engine Package					X					X																	X		X					
1-0	RCS	Engine Package					X					X																	X		X					
1-0	OMS	Engine Package					X					X																	X		X					
2-B/0	PMS	GO_2 Filter					X						X																X							
3-B/0	PMS	GH_2 Filter					X						X																X							
4-B/0	PMS	GH_2 Solenoid Valve					X						X																X							
5-B/0	PMS	GO_2 Solenoid Valve					X						X																X							
6-B	HCS	GH_2 Check Valve Package					X						X																X							
6-0	PCS	GH_2 Check Valve Package					X						X																X							
7-B	HCS	GG GH_2 Propellant Valve Pkg.					X						X																X							
7-B	OCS	GG GH_2 Propellant Valve Pkg.					X						X																X							
7-B	APU	GG GH_2 Propellant Valve Pkg.					X						X																X							
7-0	PCS	GG GH_2 Propellant Valve Pkg.					X						X																X							
8-B	HCS	GG GO_2 Propellant Valve Pkg.					X						X																X							
8-B	OCS	GG GO_2 Propellant Valve Pkg.					X						X																X							
8-B	APU	GG GO_2 Propellant Valve Pkg.					X						X																X							
8-0	PCS	GG GO_2 Propellant Valve Pkg.					X						X																X							
9-B	HCS	LH_2 Check Valve Pkg.					X						X																X							
10-B	HCS	Turbopumps					X						X																		X	X	X			
11-B	HCS	Turbopump Suction Valve Pkg.					X						X																X							
16-0	PCS	LH_2 Pump Suction Valve Pkg.					X						X																X							
12-B	HCS	GG Heat Exchanger Package					X						X																X							
13-B	HCS	LH_2 Solenoid Valve Package					X						X																X							
14-B	HCS	Gas Generator					X						X																X							

LEGEND:

RCS = Reaction Control Engine Subsystem
SEP = Separation Engine Subsystem
OMS = Orbital Maneuvering Engine Subsystem
PMS = Propellant Management Subsystem

HCS = Hydrogen Conditioning Subsystem
OCS = Oxygen Conditioning Subsystem
APU = Auxiliary Power Unit
PCS = Propellant Conditioning Subsystem

B = Booster
0 = Orbiter

TABLE IV-5 (Cont'd)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

B. AUXILIARY PROPULSION SYSTEM

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixt.	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Equipment	Cut & Braze Eqmt.	Nozzle Protect. & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press. Ox. Turbopump Hand. Eqmt	Fuel Preburner Handling Eqmt.	Ox. Preburner Handling Eqmt.	Propellant Line Handling Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv. & Press. Meas. Eqmt	Torque Meas. Device	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.
14-B	OCS	Gas Generator					X						X																							
14-B	APU	Gas Generator					X						X																							
14-0	PCS	Gas Generator					X						X																							
15-B	OCS	Compressor Inlet Valve Pkg.					X						X																							
16-B	OCS	Turbocompressor					X																											X	X	
17-B	OCS	GO_2 Check Valve Package					X						X																							
18-0	PCS	GO_2 Check Valve Package					X						X																							
18-B	HCS	Turbine					X																											X		
18-B	OCS	Turbine					X																											X		
18-B	APU	Turbine					X																											X		
15-0	PCS	Turbine					X																											X		
18/22-0/B	PMS	GH_2 Manual Valve					X						X																							
21/19-0/B	PMS	GO_2 Manual Valve					X						X																							
19/23-0/B	PMS	GH_2 Relief Valve					X						X																							
22/20-0/B	PMS	GO_2 Relief Valve					X						X																							
20/24-0/B	PMS	GH_2 QD/Solenoid Valve Pkg.					X						X																							
23/21-0/B	PMS	GO_2 QD/Solenoid Valve Pkg.					X						X																							
25-B/0	PMS	GO_2 Regulator Pkg.					X						X																							
26-B/0	PMS	GH_2 Regulator Pkg.					X						X																							
9-0	PCS	LH_2 Pump					X						X																					X		
10-0	PCS	LO_2 Pump					X						X																					X		
11-0	PCS	LO_2 Heat Exchanger					X						X																							
12-0	PCS	LH_2 Heat Exchanger					X						X																							
13-0	PCS	Power Train Unit																																X		
17-0	PCS	LO_2 Pump Suction Valve Pkg.					X						X																							

LEGEND:

RCS = Reaction Control Engine Subsystem
SEP = Separation Engine Subsystem
OMS = Orbital Maneuvering Engine Subsystem
PMS = Propellant Management Subsystem
HCS = Hydrogen Conditioning Subsystem
OCS = Oxygen Conditioning Subsystem
APU = Auxiliary Power Unit
PCS = Propellant Conditioning Subsystem
B = Booster
0 = Orbiter

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE IV-5 (Cont.)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

C. AIRBREATHING PROPULSION SYSTEM

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixt.	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand. Eqmt	Fuel Breburner Hand. Eqmt.	Ox. Preburner Hand. Eqmt.	Propellant Line Hand.Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv.& Press.Meas.Eqmt.	Boroscope, Pyro	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.	Nitrogen Serv. & Press. Eqmt.	
1-B	TFE	Turbofan Engine					X																						X							X		
2-B	APM	Inlet Valve Pkg.											X																									
3-B	APM	Fuel Dist. Valve Pkg.											X																X									
4-B	APM	Vent Valve Pkg.											X																X									
5-B	APM	Vent Disconnect Coupling					X																						X									
6-B	APM	Fill Valve																											X									
7-B	APM	Fill Coupling					X																						X									
8-B	APR	Pressure Regulator Package					X						X																									
9-B	APR	Pressurization Valve Package					X						X																									
10-B	APR	Pressurization Filter											X																									
3-O	APM	GH2 Valve Package											X																X									
5-O	APM	GO2 Valve Package											X																X									
4-O	APM	Gas Generator											X																X									
6-O	APM	LH2 Valve Package											X																X									
7-O	APM	Turbopump Assembly											X																X									
8-O	APM	Check Valve Package											X																X									
2-B/O	TFE	Fuel Control Assembly					X																						X									
3-B/O	TFE	Electronic Controller																																				

REQUIRED GSE

LEGEND: B=Booster TFE=Turbofan Engine Subsystem
O=Orbiter APM=Airbreathing Propellant Management Subsystem
APR=Airbreathing Pressurization Subsystem

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE IV-5 (Cont.)

GENERAL

GROUND SUPPORT EQUIPMENT MATRIX

for

C. AIRBREATHING PROPULSION SYSTEM

LRU NUMBER	SUBS.	DESCRIPTION	Contamination Protection Eqmt.	Valve Removal Eqmt.	Swab Sample Eqmt.	Caps	Leak Test Eqmt.	Removal & Duct Supporting Fixt.	Engine Handling Fixture	Gimbal Support Fixture	Covers or Closures	Optical Test Eqmt.	Cut and Braze Eqmt.	Nozzle Protect & Support Fixt.	L.P.T.P.A. Handling Eqmt.	H.P.T.P.A. Tooling	TPA Handling Eqmt.	Hi-Press.Ox.Turbopump Hand. Eqmt	Fuel Preburner Hand. Eqmt.	Ox. Preburner Hand. Eqmt.	Propellant Line Hand. Eqmt.	Vacuum Test Eqmt.	Bellows Compressor	Nozzle Support Eqmt.	Nozzle Positioning Eqmt.	Actuator Handling Eqmt.	Controller Handling Eqmt.	Nozzle Handling Eqmt.	Helium Serv.& Press.Meas.Eqmt.	Boroscope, Pyro	Engine Removal Fixture	Turbopump Removal Fixture	Turbopump Mounting Fixture	Cold-Gas Turbine Drive Eqmt.	Turbocompressor Removal Fixt.	A/B Engine Removal Eqmt.	Nitrogen Serv. & Press. Eqmt.			
4-B/O	TFE	Scavenge Pump											X																X										
5-B/O	TFE	Oil Boost Pump											X																X										
6-B/O	TFE	Oil Pressure Pump											X																X										
7-B/O	TFE	Oil Strainer																											X										
8-B/O	TFE	Boost Pump Relief Valve											X																X										
9-B/O	TFE	Boost Pump Regulator Valve											X																X										
10-B/O	TFE	Pressurant Regulator Valve											X																X										
11-O	TFE	Zero-G Pressurization System					X						X																								X			
12-B/O	TFE	Ignition Exciter										X																												
13-B/O	TFE	Ignition Compositor										X																												
14-B/O	TFE	Ignition Plug										X																												
15-B/O	TFE	Solid Start Cartridge																																						
N/A-B/O	TFE	Fan																												X										
N/A-B/O	TFE	Low Pressure Compressor																												X										
N/A-B/O	TFE	High Pressure Compressor																												X										
N/A-B/O	TFE	Low Pressure Turbine																												X										

LEGEND: B=Booster
O=Orbiter
TFE=Turbofan Engine Subsystem

APPENDIX A - MEASUREMENTS AND SENSORS

TABLE A-1

OCMS MEASUREMENT REQUIREMENTS

EXPLANATION OF COLUMN HEADINGS AND CODES

COLUMN HEADING	DESCRIPTION
1. IDENTITY CODE	The codes in this column relate to the measurement description given in Table A-2.
2. QUANTITY	The quantity of identical measurements (having identical description and requirements). Quantities indicated are per vehicle stage, except for engine measurements. Quantities for engine measurements are per engine.
3. RANGE & UNITS	The range of measurement and units of measure of the parameter to be measured.
4. ALLOW. ERROR	The allowable overall error between the actual parameter value and the processed data representing that value.
5. RESPONSE RATE	The maximum expected rate of change, time to change state, or frequency of variation of the parameter.
6. MTG.	Mounting of the sensor, or how the sensor is exposed to the forcing function. Codes used are: D - Direct mount. Sensing element directly exposed to the forcing function. CE - Component external. Sensor mounted on the component, with the sensing element indirectly exposed to the forcing function.
7. FLUID MEDIA	Denotes the fluid media, if any, to which the sensing element is exposed.

TABLE A-1 (cont)

OCMS MEASUREMENT REQUIREMENTS

EXPLANATION OF COLUMN HEADINGS AND CODES

COLUMN HEADING	DESCRIPTION
8. MEAS. TYPE	Relates to the sensor criteria of Table A-3, and requirements of Table A-4. The sensor criteria associated with each measurement type defines the environment, output signal characteristics, and other requirements related to the physical equipment for transducing the measured parameter to an electrical signal.
9. DATA USE	Designates the end use of the data resulting from the measurement. Where data has more than one use and the time of data activity or sample rate is different for each use, a separate line is used for each. Codes used are: M - Monitor (for failure detection) C - Control P - Performance analysis recording R - Readiness or status check T - Trend data FI - Fault isolation test W - Warning of impending failure
10. TIME OF DATA ACTIVITY	Operation or condition during which the data is meaningful.
11. SAMPLE RATE	The required rate of sampling the measurement during the time of data activity. Sampling rate is based on allowable error, response rate, and use of the data. Codes used are: AR - As required. Indicating one or several samples to be taken whenever the noted condition occurs under "time of data activity".

TABLE A-1 (cont)

OCMS MEASUREMENT REQUIREMENTS

EXPLANATION OF COLUMN HEADINGS AND CODES

COLUMN HEADING	DESCRIPTION
11. (cont)	E.O. - Each operation. Indicating one or several samples to be taken each time an operation occurs that would cause the measured parameter to change to a new value and remain at that value.
	Negl - Negligibly low sampling rate. Not important to data bus traffic or processing loads.
	TBD - Sample Rate to be determined by further study.
12.	Blank column.
13. DATA RATE	The rate at which data from each measurement is placed on the data bus during the time of data activity. For DIU's, the data rates are dependent on the data management techniques employed on a given measurement. These rates have been generated for peak traffic periods as shown in figures IV-10 through IV-15 of Section IV-B. The main engine data rates are shown in Table IV-2, and are summarized in Table IV-3.
14.	Blank column.
15. DIU NO.	Indicates the numerical identification of the DIUs to which a measurement is assigned. Assignments have been made on the orbiter using criteria discussed in Section IV-B. The DIUs for the main and airbreathing engines are their respective engine controllers.
16. REMARKS	Comments used to provide additional information on a parameter. An asterik in this column indicates that the remark expands on information contained in another asterisked column on the same line.

TABLE A-1 (cont)

OCMS MEASUREMENT REQUIREMENTS

EXPLANATION OF COLUMN HEADINGS AND CODES

Glossary of Additional Symbols

PSIA	Pounds per square inch, absolute
PSID	Pounds per square inch, differential
PSIG	Pounds per square inch, gage
°R	Degrees, Rankin
°F	Degrees, Fahrenheit
O/C	Open/closed
sec	Second
F.S.	Full scale
S/S	Steady-state
T/C	Time constant
MS	Millisecond
VDC	Volts direct current
μ	Micron
RPM	Revolutions per minute
TBD	To be determined
HZ	Hertz
M.R.	Mixture ratio
(A)	Analog
(D)	Discrete
N/A	Not applicable
lb.	Pound
C/U	Covered/uncovered
" = in	Inch
K =	1000

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
PfLPTPAs	2	0-50 PSIA	±0.5%	10 HZ	D	LH2	P-1-ME	C	Start	20/sec				Eng. Cont.	
								M	Start, S/S, Shutdown	20/sec					Start & POGO Monitor
								P	Start	20/sec					
								FI	PfLPTPAd Out-Of-Limits						
									and per FMEAs.	A.R.					
PfLPTPATi	1	0-3000 PSIA	±1.0%	< 20HZ	D	LH2	P-2-ME	M	Start, S/S, Shutdown	20/sec					Start Monitor
								T	Start	20/sec					
								FI	Fuel Recirc. Regulator						
									and per FMEA	A.R.					
PfLPTPAd	1	0-100 PSIA	±1.0%	F.S. in 2 sec	D	LH2	P-3-ME	M	Start, S/S, Shutdown	20/sec					Start Monitor
								T	S/S	20/sec					
								P	Start	20/sec					
								FI	PfHPTPAd Out-Of-Limit						
									and per FMEAs	A.R.					
PcFPB	1	0-6000 PSIA	±0.5%	F.S. in 2 sec	D	Hot H_2	P-4-ME	C	Start, Shutdown	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								P	Start	20/sec					Start Analysis
								FI	PcMCC Out-Of-Limits						
									and per FMEAs	A.R.					
PoLPTAs	2	0-300 PSIA	±0.5%	10HZ	D	LO2	P-5-ME	C	Start	20/sec					
								M	Start, S/S, Shutdown	20/sec					Start & POGO Monitor
								P	Start	20/sec					
								FI	PoLPTPAd Out-Of-Limit						
									and per FMEA	A.R.					
PoLPTPAd	1	0-750 PSIA	±1.0%	F.S. in 2 sec	D	LO2	P-6-ME	M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								P	Start	20/sec					Start Analysis
								FI	PoHPTPAd Out-Of-Limit						
									and per FMEAs.	A.R.					
PcOPB	1	0-6000 PSIA	±0.5%	F.S. in 2 sec	D	Hot H_2	P-4-ME	C	Start, Shutdown	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								P	Start	20/sec					
								FI	PcMMC Out-Of-Limit						
									& per FMEA	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
PheHPOTPA	2	0-50 PSIA	±1.5%	<10HZ	D	GHE	P-7-ME	C	Start	20/sec				Eng. Cont.	
								M	Start, S/S, Shutdown	20/sec					
								W	Seal Failure	20/sec					Flight Safety
								FI	HPOTPA Cavity Seal	A.R.					
PoHPTPATB	2	0-8000 PSIA	±1.5%	Est. >20HZ	D	LO2	P-8-ME	M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								W	Start, S/S, Shutdown	20/sec					Flight Safety
								FI	PoHPTPAd Out-Of-Limit	A.R.					
PcMCC	2	0-3500 PSIA	±0.5%	F.S. in 2 sec	D	Hot Gas	P-4-ME	C	Start, S/S, Shutdown	20/sec					Thrust
								M	Start, S/S, Shutdown	20/sec					
								P	Start, S/S	20/sec					
								W	Pc Out-Of-Limits	20/sec					
								FI	Thrust Out-Of-Limit	A.R.					
PvacFL-(1-4)	8	0-100 μ	±20%	1HZ	D	VAC to LH2	P-9-ME	C	Start	20/sec					
								M	Start, S/S, Shutdown	20/sec					Start Monitor
								T	Start, S/S, Shutdown	20/sec					
								FI	VAC.Jacket Leak	A.R.					
PoPBFMo	1	0-8000 PSIA	±0.5%	10-20HZ	D	LO2	P-8-ME	C	Start, S/S, Shutdown	100/sec					M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	Start, S/S	100/sec					
								FI	PcOPB and PcFPB						
									Out-Of-Limit	A.R.					
PoMCCFMo	1	0-5000 PSIA	±0.5%	10-20HZ	D	LO2	P-8-ME	C	Start, S/S, Shutdown	100/sec					M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	Start, S/S	100/sec					
								FI	PcMCC Out-Of-Limits	A.R.					
PfFPBi	1	0-7000 PSIA	±0.5%	10-20HZ	D	LH2	P-10-ME	C	Start, S/S, Shutdown	100/sec					M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	Start, S/S	100/sec					
								FI	PcFPB Out-Of-Limit	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

FOLDOUT FRAME 1

FOLDOUT FRAME 2 A-9 and A-10

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
PfOPBi	1	0-7000 PSIA	±0.5%	10-20HZ	D	LH2	P-10-ME	C	Start, S/S, Shutdown	100/sec				Eng. Cont.	M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	S/S	100/sec					
								FI	PcOPB Out-Of-Limit	A.R.					
Δ PfFPBI/C	2	0-1000 PSID	±0.75%	10-20HZ	D	LH2/Gas	P-11-ME	C	Start, S/S, Shutdown	100/sec					Redundant M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	S/S	100/sec					
								FI	PcFPB Out-Of-Limit	A.R.					
Δ PfOPBI/C	2	0-1500 PSID	±0.75%	10-20HZ	D	LH2/Hot Gas	P-11-ME	C	Start, S/S, Shutdown	100/sec					Redundant M.R.
								M	Start, S/S, Shutdown	100/sec					
								P	S/S	100/sec					
								FI	PcOPB Out-Of-Limit	A.R.					
Δ PCI/G	1	0-200 PSID	±2.0%	<1HZ	D	LH2/Hot Gas	P-12-ME	M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								W	Start, S/S (Out-Of-Limit)	20/sec					Flight Safety
								FI	Per FMEA 1.1.1.7	A.R.					
PoHEo	1	0-1500 PSIA	±0.5%	F.S. in 2 sec	D	GO2, AMB.	P-13-ME	M	Start, S/S, Shutdown	20/sec					Autogenous System
								T	Start, Shutdown	20/sec					
								R	Check Valve Verif.						
									During Load & Purge	E.O.					
								FI	PoT-1 Out-Of-Limit	A.R.					
PfNCo	1	0-1500 PSIA	±0.5%	F.S. in 2 sec	D	GH2, Amb.	P-13-ME	M	Start, S/S, Shutdown	20/sec					Autogenous System
								T	Start, Shutdown	20/sec					
								R	Check Valve Verif.						
									During Load & Purge	E.O.					
								FI	PfT-1 Out-Of-Limit	A.R.					
PheFTPCVi	1	0-2000 PSIA	±0.5%	F.S. in 1 sec	D	GHe, GH2	P-13-ME	C	Start, Shutdown	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								T	Start, Shutdown	20/sec					
								R	CK. Valve Verification	A.R.					
								FI	Fuel Purge CK. Valve	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

A-11 and A-12
(Continued)

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
PheOTPCVi	1	0-2000 PSIA	±0.5%	F.S. in 1 sec	D	GHe, GO2	P-13-ME	C	Start, Shutdown	20/sec				Eng. Cont.	
								M	Start, S/S, Shutdown	20/sec					
								T	Start, Shutdown	20/sec					
								R	CK. Valve Verification	A.R.					
								FI	Oxid. Purge CK. Valve	A.R.					
PhePBSVo	1	0-2000 PSIA	±0.5%	F.S. in 1 sec	D	GHe, GO2	P-13-ME	C	Start, Shutdown	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								T	Start, Shutdown	20/sec					
								R	CK. Valve Verification	A.R.					
								FI	Preb. Purge CK. Valves	A.R.					
PPS	1	0-1500 PSIA	±1.5%	< 10HZ	D	GHe, GN_2	P-14-ME	C	Start, Shutdown	20/sec					
								M,T	Start, S/S, Shutdown	20/sec					Start Monitor
								R	Start, Load, Purge	E.O.					
								FI	Purge Select Valve No-Go	A.R.					
PhS	2	Not Available		10HZ	D	Hydraul.	P-15-ME	C	Start, S/S, Shutdown	20/sec					
								M,T	Start, S/S, Shutdown	20/sec					
								R	Preflight	E.O.					
								FI	Gimbal Failure	A.R.					
PhA	2	Not Available		10HZ	D	GN2	P-15-ME	C	Start, S/S, Shutdown	20/sec					
								M,T	Start, S/S, Shutdown	20/sec					
								R	Preflight	E.O.					
								FI	Gimbal Failure	A.R.					
Δ PGAP	1	Not Available		10HZ	D	Hydraul.	P-15-ME	M	Start, S/S, Shutdown	100/sec					
								T	S/S	100/sec					
								FI	Pitch Gimbal Failure	A.R.					
Δ PGAY	1	Not Available		10HZ	D	Hydraul.	P-15-ME	M	Start, S/S, Shutdown	100/sec					
								T	S/S	100/sec					
								FI	Yaw Gimbal Failure	A.R.					
Δ PHF	1	Not Available		10HZ	D	Hydraul	P-15-ME	M,T	Start, S/S, Shutdown	100/sec					
								FI	Filter Failure	A.R.					
PoHPTPA(S2)d	1	0-8000 PSIA	±5%	10-20 HZ	D	LO2	P-8-ME	C	Start, S/S, Shutdown	100/sec					Back-up M.R.
								M	Start, S/S, Shutdown	100/sec					
								FI	FMOPB Out-Of-Limits and per FMEA.	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
PoHPTPA(S1)d	1	0 5000 PSIA	±0.5%	10-20 HZ	D	LO2	P-8-ME	C	Start, S/S, Shutdown	100/sec				Eng. Cont.	Back-up M.R.
								M	Start, S/S, Shutdown	100/sec					
								FI	PoMCCFMo Out-Of-Limit						
									and per FMEA	A.R.					
TcFPB	1	460-2200°R	±3°F	0.5 sec 1 T/C	D	Hot H_2	T-16-ME	M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								FI	PcMCC Out-Of-Limit						
									and per FMEA	A.R.					
TcOPB	1	460-2200°R	±3°F	0.5 Sec 1 T/C	D	Hot H2	T-16-ME	M	Start, S/S, Shutdown	20/sec					
								T	S/S	20/sec					
								FI	PcMCC Out-Of-Limit						
									and per FMEA	A.R.					
ToPBFMo	1	160-260°R	±0.6°F	0.5 sec 1 T/C	D	LO2	T-17-ME	C	Start, S/S, Shutdown	20/sec					M.R.
								P	S/S	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								FI	FMOPB Out-Of-Limit	A.R.					
TfLPTPAs	2	30-50°R	±0.3°F	0.5 sec 1 T/C	D	LH2	T-17-ME	C	Start	20/sec					Start Analysis
								M	Start, S/S, Shutdown	20/sec					
								R	Propellant Load	E.O.					
								FI	PfLPTPAd Out-Of-Limit						
									and per FMEA	A.R.					
TfFRL	1	30-50°R	±0.3°F	0.5 sec 1 T/C	D	LH2	T-17-ME	C	Prestart	20/sec					
								M,T	Prestart	20/sec					
ToMCCFMo	1	160-260°R	±0.6°F	0.5 sec 1 T/C	D	LO2	T-17-ME	C	Start, S/S, Shutdown	20/sec					M.R.
								P	S/S	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								FI	FMOMCC Out-Of-Limit	A.R.					
TfFPBi	1	100-300°R	±0.6°F	0.5 sec 1 T/C	D	H2	T-17-ME	C	Start, S/S, Shutdown	20/sec					M.R.
								M	Start, S/S, Shutdown	20/sec					
								P	S/S	20/sec					
								FI	PcFPB Out-Of-Limit						
									and per FMEA	A.R.					
TfOPBi	1	100-300°R	±0.6°F	0.5 sec 1 T/C	D	H2	T-17-ME	C	Start, S/S, Shutdown	20/sec					Back-up M.R.
								M	Start, S/S, Shutdown	20/sec					
								FI	PcOPB Out-Of-Limit						
									and per FMEA	A.R.					

* Per Engine   ** See Main Engine Data Rate Analysis, Table IV-2

FOLDOUT FRAME 1 FOLDOUT FRAME 2

A-15 and A-16
(Continued)

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
ToLPTPAs	2	160-180°R	±0.6°F	0.5 sec 1 T/C	D	LO2	T-17-ME	C	Start	20/sec				Eng. Cont.	Start Analysis
								M	Start, S/S, Shutdown	20/sec					
								R	Propellant Load	E.O.					
								FI	PoLPTPAd Out-Of-Limit						
									and per FMEA	A.R.					
TfFMVo	1	30-300°R	±2°F	0.5 sec 1 T/C	D	LH2	T-17-ME	M	Pre-Start, Post-Burn	20/sec					
								FI	Fuel Main Valve LK.						
									or Autog. CK Valve LK.	A.R.					
ToOMVo	1	160-350°R	±2°F	0.5 sec 1 T/C	D	LO2	T-17-ME	M	Pre-start, Post-Burn	20/sec					
								FI	Leakage Detected	A.R.					
								FI	Oxid. Main Valve Lk.						
									or Autog. Ck. Valve Lk.	A.R.					
TeNCVd	1	30-300°R	±2°F	0.5 sec 1 T/C	D	LH2	T-17-ME	M	Pre-start, Post-Burn	20/sec					
								FI	Nozz. Cool. Valve Leak.	A.R.					
LFMV(A)	1	0-100%	±1.0%	F.S. in 0.4sec	CE	-	PN-18-ME	T	Start, Shutdown	100/sec					
								P	Start	100/sec					
LOMV(A)	1	0-100%	±1.0%	F.S. in 1.0 sec	CE	-	PN-18-ME	T	Start, Shutdown	20/sec					
								P	Start	20/sec					
LOPBFCV(A)	2	0-100%	±1.0%	10HZ Resp.	CE	-	PN-18-ME	C	Start, S/S, Shutdown	100/sec					
								M	Start, S/S, Shutdown	100/sec					
								T	Start, S/S, Shutdown	100/sec					
								P	Start	100/sec					
LOPBOCV(A)	2	0-100%	±1.0%	10HZ Resp.	CE	-	PN-18-ME	C	Start, S/S, Shutdown	100/sec					
								M	Start, S/S, Shutodwn	100/sec					
								T	Start, S/S, Shutdown	100/sec					
								P	Start	100/sec					
LFPBOCV(A)	2	0-100%	±1.0%	10HZ Resp	CE	-	PN-18-ME	C	Start, S/S, Shutdown	100/sec					
								M	Start, S/S, Shutdown	100/sec					
								T	Start, S/S, Shutdown	100/sec					
								P	Start	100/sec					
LORSV(A)	1	0-100%	±1.0%	F.S. in 1 sec	CE	-	P-18-ME	T	Start, Shutdown	20/sec					
								P	Start	20/sec					
LFRSV(A)	1	0-100%	±1.0%	F.S. in 1 sec	CE	-	PN-18-ME	T	Start, Shutdown	20/sec					
								P	Start	20/sec					
LFRCV(A)	1	0-100%	±1.0%	F.S. in 1 sec	CE	-	PN-18-ME	T	Start, Shutdown	20/sec					
	1				CE	-		P	Start	20/sec					
LGAY(A)	1	100-0-100%	±1.0%	10HZ Resp	CE	-	PN-18-ME	T	Mainstage	100/sec					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

A-17 and A-18

(Continued)

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
LGAP(A)	1	100-0-100%	+1.0%	10HZ Resp.	CE	-	PN-18-ME	T	Mainstage	100/sec				Eng. Cont.	
LEN(A)	1	0-100%	+1.0%	F.S. in 8 sec	CE	-	PN-18-ME	M	Pre-Start, Post-Burn	20/sec					Orbiter Only
								T	S/S	20/sec					
LFMV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O					
								FI	PfFPBi and PfOPBi						
									No-Go	A.R.					
LOMV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PcMCC No-Go	A.R.					
LOPBFCV(D)	2	On/Off	4MC	-	CE	-	PN-19-ME	C	Start	E.O.					
								R	Load & Purge	E.O.					
								FI	PcOPB No-Go	A.R.					
LOPBOCV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start	E.O.					
								R	Load & Purge	E.O.					
								FI	PcOPB No-Go	A.R.					
LFPBOCV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start	E.O.					
								R	Load & Purge	E.O.					
								FI	PcFPB No-Go	A.R.					
LORSV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PoLPTPAd No-Go	A.R.					
LFRSV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PfLPFTPATi No-Go	A.R.					
LFRCV(D)	2	On/Off	4MS	-	CE	-	PN-19-ME	C	Start, Shutdown	E.O					
								R	Load & Purge	E.O.					
								FI	TfFRL No-Go	A.R.					
LIOVOPB(D)	2	On/Off	-	30-50 MSEC	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	OPB Ignition Failure	A.R.					
								T	Start	E.O.					Compute oper. time
LIOVFPB(D)	2	On/Off	-	30-50 MSEC	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	FPB Ignition Failure	A.R.					
								T	Start	E.O.					Compute oper. time

* Per Engine   ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
LIOVMCC(D)	2	On/Off	-	30-50 MSEC	CE	-	PN-19-ME	C	Start, Shutdown	E.O.				Eng. Cont.	
								R	Load & Purge	E.O.					
								FI	MCC Ignition Failure	A.R.					
								T	Start	E.O.					Compute oper. time
LPOPSV(D)	1	On/Off	-	TBD	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PhePBSVo No-Go	A.R.					
								T	Start, Shutdown	E.O.					Compute oper. time
LMOPSV(D)	1	On/Off	-	TBD	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PheOTPCVi No-Go	A.R.					
								T		E. O.					Compute oper. time
LMFPSV(D)	1	On/Off	-	TBD	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								R	Load & Purge	E.O.					
								FI	PheFTPCVi No-Go	A.R.					
								T	Start, Shutdown	E.O.					Compute oper. time
LHSCPSV(D)	1	On/Off	-	TBD	CE		PN-19-ME	R	Pre-Load	E.O.					
								C	Pre-Start, Purge	E.O.					
								W	Closure During Sys. Oper.	A.R.					Flight Safety
								FI	PheHPOTPA No-Go	A.R.					
LESPSV(D)	2	On/Off	-	TBD	CE	-	PN-19-ME	R	Pre-Load	E.O.					
								C	Pre-Start	E.O.					
								FI	PoLPTPAs and PfLPTPAs						
									Out-Of-Limits	A.R.					
LPSV(D)	2	On/Off	-	TBD	CE	-	PN-19-ME	R	Pre-Load	E.O.					
								C	Pre-Start	E.O.					
								FI	PPS No-Go	A.R.					
LENCV(D)	2	On/Off	-	TBD	CE	-	PN-19-MR	C	Start, Shutdown	E.O.					Orbiter Only
								R	Load & Purge	E.O.					
								FI	TENCV No-Go	A.R.					
								T	Start, Shutdown	E.O.					Compute oper. time
LENA(D)	2	On/Off	-	TBD	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					Orbiter Only
LENB(D)	2	On/Off	-	TBD	CE	-	PN-19-ME	C	Start, Shutdown	E.O.					Orbiter Only
LENC(D)	2	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.O.					Orbiter Only

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
LENLA(D)	1	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.O.				Eng. Cont.	Orbiter Only
								W	2 or More Locks Fail	A.R.					Flight Safety
								T	Start, Shutdown	E.O.					
								FI	LENA No-Go	A.R.					
LENLB(D)	1	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.O.					Orbiter Only
								W	2 or more locks fail	A.R.					Flight Safety
								T	Start, Shutdown	E.O.					
								FI	LENB No-Go	A.R.					
LENLC(D)	1	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.0					Orbiter Only
								W	2 or more locks fail	A.R.					Flight Safety
								T	Start, Shutdown	E.O.					
								FI	LENC No-Go	A.R.					
LNLP(D)	2	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								W	Lock Failure	A.R.					Flight Safety
								T	Start, Shutdown	E.O.					
								FI	Lock Failure	A.R.					
LNLY(D)	2	On/Off	-		CE	-	PN-19-ME	C	Start, Shutdown	E.O.					
								W	Lock Failure	A.R.					Flight Safety
								T	Start, Shutdown	E.O.					
								FI	Lock Failure	A.R.					
IIMCC	1	TBD	±5%	< 10MS	-	-	CU-24-ME	M	Start	20/sec					
								T	Start	20/sec					
								FI	MCC Ignition Failure	A.R.					
IIOPB	1	TBD	±5%	< 10MS	-	-	CU-24-ME	M	Start	20/sec					
								T	Start	20/sec					
								FI	OPB Ignition Failure	A.R.					
IIFPB	1	TBD	±5%	< 10MS	-	-	CU-24-ME	M	Start	20/sec					
								T	Start	20/sec					
								FI	FPB Ignition Failure	A.R.					
NLPFTPA	1	0-10K RPM	±1%	F.S. in 2 sec	CE	-	SP-24-ME	M	Start, S/S, Shutdown	20/sec					
								P	Start	20/sec					Start Analysis
								FI	PfLPTPAd Out-Of-Limit						
									and per FMEA	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

A-23 and A-24
(Continued)

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1.4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
NHPFTPA	1	0-30K RPM	±1%	F.S. in 2 sec	CE	-	SP-24-ME	M	Start, S/S, Shutdown	100/sec				Eng. Cont.	
								T	S/S	100/sec					
								P	Start	100/sec					Start Analysis
								FI	PfFPBi and PfOPBi Out-Of-						
									Limit & Per FMEA	A.R.					
NLPOTPA	1	0-4000 RPM	±1%	F.S. in 2 sec	CE	-	SP-24-ME	M	Start, S/S, Shutdown	20/sec					
								C	Start, S/S	20/sec					Back-up Flow
								P	Start	20/sec					Start Analysis
								FI	PoLPTPAd Out-Of-Limit						
									and per FMEA	A.R.					
NHPOTPA	1	0-20K RPM	±1%	F.S. in 2 sec	CE	-	SP-24-ME	M	Start, S/S, Shutdown	100/sec					
								T	S/S	100/sec					
								P	Start	100/sec					Start Analysis
								C	Start, S/S	100/sec					Back-up Flow
								FI	PoHPTPAd Out-Of-Limit						
									and per FMEA	A.R.					
ALPFTPA	2	TBD	TBD	TBD	CE	-	V-20-ME	M	Mainstage	100/sec					
								FI	TP Bearing Wear	100/sec					
								T	S/S	100/sec					
								W	Impending TP Failure	A.R.					Flight Safety
AHPFTPA	2	TBD	TBD	TBD	CE	-	V-20-ME	M	Mainstage	100/sec					
								FI	TP Bearing Wear	100/sec					
								T	S/S	100/sec					
								W	Impending TP Failure	A.R.					Flight Safety
ALPOTPA	2	TBD	TBD	TBD	CE	-	V-20-ME	M	Mainstage	100/sec					
								W	Impending Failure	100/sec					Flight Safety
								FI	TP Bearing Wear	100/sec					
								T	S/S	100/sec					
AHPOTPA	2	TBD	TBD	TBD	CE	-	V-20-ME	M	Mainstage	100/sec					
								W	Impending TP Failure	100/sec					Flight Safety
								T	S/S	100/sec					
								FI	TP Bearing Wear	100/sec					
FMOPB	2	150 lbs/sec	±0.75%	10HZ	D	LO2	F-24-ME	C	Start, S/S, Shutdown	100/sec					M.R.
								P	S/S	100/sec					
								FI	PoPBFMo Out-Of-Limit						
									and per FMEA	A.R.					

* Per Engine ** See Main Engine Data Rate Analysis, Table IV-2

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.1, 4.1 Main Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	INTERNAL SAMPLE RATE		** DATA RATE		DIU NO.	REMARKS
FMOMCC	2	800 lbs/sec	±0.75%	10HZ	D	LO2	F-24-ME	C	Start, S/S, Shutdown	100/sec				Eng. Cont.	
								P	S/S	100/sec					
								PI	PcMCC Out-Of-Limit						
									and per FMEA	A.R.					
DIOPB	2	TBD	TBD	5MS	D	Hot H2	D-22-ME	C	Start	E.O.					
								W	OPB Ignition Failure	A.R.					Flight Safety
								FI	OPB Ignition Failure	A.R.					
								T	Start	E.O.					
DIFPB	2	TBD	TBD	5MS	D	Hot H2	D-22-ME	C	Start	E.O.					
								W	FPB Ignition Failure	A.R.					Flight Safety
								FI	FPB Ignition Failure	A.R.					
								T	Start	E.O.					
DIMCC	2	TBD	TBD	5MS	D	Hot H2	D-22-ME	C	Start	E.O.					
								W	MCC Ignition Failure	A.R.					Flight Safety
								FI	MCC Ignition Failure	A.R.					
								T	Start	E.O.					
QhHSR	2	0-100%	±2%	TBD	D	Hydr.	Q-24-ME	C	Start, S/S, Shutdown	20/sec					
								M	Start, S/S, Shutdown	20/sec					
								FI	PhS Out-Of-Limits	A.R.					
FMOPBhe	1	0.1 lb/sec	±5%	5 MS F.S.	D	GHe,GO2	F-23-ME	C	Start, S/S/,Shutdown	E.O.					
								T	Shutdown	E.O.					
FMFPBhe	1	0.1 lb/sec	±5%	5 MS F.S.	D	GHe,GO2	F-23-ME	C	Start, S/S, Shutdown	E.O.					
								T	Shutdown	E.O.					

* Per Engine   ** See Main Engine Data Rate Analysis, Table IV-2

FOLDOUT FRAME 1

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

FOLDOUT FRAME 2
A-27 and A-28

SUBSYSTEM: 1.2 Boost. Main Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoT-1	2	0-50 PSIA	±2 PSIA	20 PSI/GHe	D	GO2,GHe	P-1	C	LO2 Pressurization	10/sec					T-1 (A&B) Ullage
								R	Load & Purge	A.R.					
								M,C	Main Engine Burn, Shutdown	1/sec					
								M	Ferry, MPS Secured	NEGL.					
PoL-1,2	4	0-100 PSIA	±5 PSIA	20 PSI/sec	D	LO2	P-2	R	Load & Purge	A.R.					L-8,9 (A&B)
								FI	Low Engine Thrust	A.R.					
PoF-1	2	0-100 PSIA	±5 PSIA	20 PSI/sec	D	LO2	P-3	R	LO2 Load	A.R.					L-11 (A&B)
								FI	Slow LO2 Fill	A.R.					
PfT-1	2	0-50 PSIA	±2 PSIA	20 PSI/sec	D	GH2,GHe	P-1	C	LH2 Pressurization	10/sec					T-2 (A&B) Ullage
								R	Load & Purge	A.R.					
								M,C	Main Engine Burn, Shutdown	1/sec					
								M	Ferry, MPS Secured	NEGL.					
PfF-1	2	0-100 PSIA	±5 PSIA	20 PSI/sec	D	LH2	P-2	R	LH2 Load	A.R.					L-21 (A&B)
								FI	Slow LH2 Fill	A.R.					
ToT-1	2	0-700°R	±5°R	20°R/sec	D	GO2,GHe	T-2	R	Load & Purge	A.R.					T-1 (A&B) Ullage
								FI	PoT-1 Out-Of-Limit	A.R.					
								M	System Active	1/sec					
ToL-1,2	4	0-700°R	±5°R	20°R/sec	D	LO2	T-2	R	Load & Purge	A.R.					L-8,9 (A&B)
								FI	PoL-1,2 Out-Of-Limit	A.R.					
TfT-1	2	0-700°R	±5°R	20°R/sec	D	GH2,GHe	T-2	R	Load & Purge	A.R.					T-2 (A&B) Ullage
								FI	PfT-1 Out-Of-Limit	A.R.					
								M	System In Use	1/sec					
TfF-1	2	0-700°R	±5°R	20°R/sec	D	LH2	T-2	R	Load	A.R.					Downstream V-19 (A&B)
								FI	PfF-1 Out-Of-Limits	A.R.					
QoT-1	2	C/U	±0.13"	0.001 sec	D	LO2	L-1	C	LO2 Load	10/sec					T-1(A&B) Bottom
								C	Main Engine Burn	10/sec					After QoT-2 Uncovers
QoT-2	2	C/U	±0.13"	0.001 sec	D	LO2	L-1	C	LO2 Load	10/sec					T-1 (A&B) Middle
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					
QoT-3	2	C/U	±0.13"	0.001 sec	D	LO2	L-1	C	LO2 Load	10/sec					T-1 (A&B) TOP
								R	Load	A.R.					
QfT-1	2	C/U	±0.13"	0.001 sec	D	LH2	L-1	C	LH2 Load	10/sec					T-2 (A&B) Bottom
								C	Main Engine Burn	10/sec					After QfT-2 Uncovers
								R	Load	A.R.					
QfT-2	2	C/U	±0.13"	0.001 sec	D	LH2	L-1	C	LO2 Load	10/sec					T-2 (A&B) Middle
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.2 Boost. Main Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
QfT-3	2	C/U	±0.13"	0.001 sec	D	LH2	L-1	C	LH2 Load	10/sec					T-2 (A&B) TOP
								R	Load	A.R.					
LOP-(1-7)	14	O/C	-	0.5 sec	CE	-	PN-2A	R	Per Pos. Status List	A.R.					V-(77-83) A&B
								FI	Low Engine Thrust	A.R.					
LOIV-1,2	4	O/C	-	0.5 sec	CE	-	PN-2A	R	Per Pos. Status List	A.R.					V-1,2 A&B
								FI	Improper Fill Rate	A.R.					
								FI	Low Engine Thrust	A.R.					
LOVV-(1-4)	8	O/C	-	0.3 sec	CE	-	PN-2	R	LO2 Load & Purge	E.O.					V-(3-6) A&B
								FI	PoT-1 Out of Limit	A.R.					
LOFV-1	2	O/C	-	0.5 sec	CE	-	PN-2A	R	LO2 Load & Purge	E.O.					V-7 A&B
								FI	Improper Fill Rate	A.R.					
LFIV-(1-7)	14	O/C	-	0.5 sec	CE	-	PN-2A	R	Per Pos. Status List	A.R.					V-(8-14) A&B
								FI	Low Engine Thrust	A.R.					
LFVV-(1-4)	8	O/C	-	0.3 sec	CE	-	PN-2	R	LH2 Load & Purge	A.R.					V-(15-18) A&B
								FI	PfT-1 Out of Limits	A.R.					
LFFV-1	2	O/C	-	0.5 sec	CE	-	PN-2A	R	LH2 Load & Purge	A.R.					V-19 A&B
								FI	Improper Fill Rate	A.R.					
LOFC-1	2	O/C	-	-	CE	-	PN-3	R	LO2 Load & Purge	E.O.					C-1 A&B
								FI	PoF-1 Out of Limits	A.R.					
LHC-1,2	4	O/C	-	-	CE	-	PN-3	R	LO2 Recirculation	E.O.					C-2 A&B
								FI	PgRL-1 Out of Limits	A.R.					
LFVC-1	2	O/C	-	-	CE	-	PN-3	R	LH2 Load & Purge	E.O.					C-3 A&B
								FI	PfT-1 Out of Limits	A.R.					
LFFC-1	2	O/C	-	-	CE	-	PN-3	R	LH2 Load & Purge	E.O.					C-5 A&B
								FI	PfF-1 Out of Limits	A.R.					
VOP-(1-7)	14	0/28VDC	±20%	-	-	-	EX-1	FI	LOP-(1-7) No-Go	A.R.					V-(77-83) A&B
VOIV-1,2	4	0/28VDC	±20%	-	-	-	EX-1	FI	LOIV-1,2 No-Go	A.R.					V-1,2 A&B
VOVV-(1-4)	8	0/28VDC	±20%	-	-	-	EX-1	FI	LOVV-(1-4) No-Go	A.R.					V-(3-6) A&B
VOFV-1	2	0/28VDC	±20%	-	-	-	EX-1	FI	LOFV-1 No-Go	A.R.					V-7 A&B
VFIV-(1-7)	14	0/28VDC	±20%	-	-	-	EX-1	FI	LFIV-(1-7) No-Go	A.R					V-(8-14) A&B
VFVV-(1-4)	8	0/28VDC	+20%	-	-	-	EX-1	FI	LFVV-(1-4) No-Go	A.R.					V-(15-18) A&B
VFFV-1	2	0/28VDC	±20%	-	-	-	EX-1	FI	LFFV-1 No-Go	A.R.					V-19 A&B
PgRL-1	2	0-200 PSIA	±2 PSIA	20 PSI/sec	D	LO2,GHe	P-3	M	LO2 Load	1/sec					L-12 A&B
								R	Load & Purge	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.2 Boost. Main Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoS-(1-7)	14	0-200 PSIA	±2 PSIA	20 PSI/sec	D	LO2	P-3	R	Load & Purge	E.O.					L-(1-7) A&B
								M	Engine Operating	1/sec					
								FI	PoLPTPAs Out-Of-Limit	A.R.					
PfS-(1-7)	14	0-200 PSIA	±2 PSIA	20 PSI/sec	D	LH2	P-3	R	Load & Purge	E.O.					L-(13-19) A&B
								M	Engine Operating	1/sec					
								FI	PfLPTPAs Out-Of-Limit	A.R.					
ToS-(1-7)	14	0-600°R	±5°R	20°R/sec	D	LO2	T-2	R	Load & Purge	E.O.					L-(1-7) A&B
								M	Engine Operating	1/sec					
								FI	ToLPTPAs Out-Of-Limit	A.R.					
TfS-(1-7)	14	0-600°R	±5°R	20°R/sec	D	LH2	T-2	R	Load & Purge	E.O.					L-(13-19) A&B
								M	Engine Operating	1/sec					
								FI	TfLPTPAs Out-Of-Limit	A.R.					
TgO-(1-7)	14	0-700°R	±5°R	20°R/sec	D	GO2	T-2	M	Engine Operating	1/sec					Autogenous Interface
								FI	ToT-1 Out-Of-Limit	A.R.					
TgF-(1-7)	14	0-700°R	±5°R	20°R/sec	D	GH2	T-2	M	Engine Operating	1/sec					Autogenous Interface
								FI	TfT-1 Out-Of-Limit	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 1.3 Booster Main Press.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PgO-8	2	0-1200 PSIA	±10PSIA	500 PSI/sec	D	GO2	P-6A	R	Main Engine Operation	A.R.					Upstream F-1, A&B
								FI	PoT-1 Out-Of-Limits	A.R.					
PgO-9	2	0-1200 PSIA	±10 PSIA	500 PSI/sec	D	GO2	P-6A	R	Main Engine Operation	A.R					Downstream F-1, A&B
								FI	PoT-1 Out-Of-Limits	A.R					
PgO-10	2	0-1200 PSIA	±10 PSIA	500 PSI/sec	D	GO2	P-6A	R	Main Engine Operation	A.R.					L-24, A&B
								FI	PoT-1 Out-Of-Limits	A.R.					
PgF-8	2	0-1200 PSIA	±10 PSIA	500 PSI/sec	D	GH2	P-6A	R	Main Engine Operation	A.R.					Upstream F-2, A&B
								FI	PfT-1 Out-Of-Limits	A.R.					
PgF-9	2	0-1200 PSIA	±10 PSIA	500 PSI/sec	D	GH2	P-6A	R	Main Engine Operation	A.R.					Downstream F-2, A&B
								FI	PfT-1 Out-Of-Limits	A.R.					
PgF-10	2	0-1200 PSIA	±10 PSIA	500 PSI/sec	D	GH2	P-6A	R	Main Engine Operation	A.R.					L-23, A&B
								FI	PfT-1 Out-Of-Limits	A.R.					
LOPCV-1,2	4	O/C	-	0.5 sec	CE	GO2	PN-2A	R	Per Pos. Status List	A.R.					V-20,21 A&B
								FI	PoT-1 Out-Of-Limits	A.R.					
LFPCV-1,2	4	O/C	-	0.5 sec	CE	GH2	PN-2A	R	Per Pos. Status List	A.R.					V-22,23 A&B
								FI	PfT-1 Out-Of-Limits	A.R.					
LHC-3,4	4	O/C	-	-	CE	GH2,GHe	PN-3A	R	Load & Purge	E.O.					C-4, A&B
								FI	PfT-1 Out-Of-Limits	A.R.					
LHC-5,6	4	O/C	-	-	CE	GO2,GHe	PN-3A	R	Load & Purge	E.O.					C-6, A&B
								FI	PoT-1 Out-Of-Limits	A.R.					
VOPCV-1,2	4	0/28VDC	±20%	-	-	-	EX-1	FI	LOPCV-1,2 No-Go	A.R.					V-20,21 A&B
VFPCV-1,2	4	0/28VDC	±20%	-	-	-	EX-1	FI	LFPCV-1,2 No-Go	A.R.					V-22,23 A&B

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.1 Booster RCS Engine

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
Pc-(21-38)	18	0-450 PSIA	±2 PSIA	50,000 PSI/sec	D	Hot Gas	P-4	C	RCS Engine Start	A.R.					Thruster-(21-38)
								M	RCS Engine Burn	20/sec					
								FI	RCS Engine No-Go	A.R.					
LBIV-(21-38)	18	O/C	-	0.5 sec	CE	-	PN-2A	R	Load, Purge, Launch, Secure	A.R.					Thruster-(21-38)
								FI	Pc-(21-38) No-Go	A.R.					
LMBV-(21-38)	18	O/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.					Thruster - (21-38)
								R	RCS Engine Burn	E.O.					
								FI	Pc-(21-38) No-Go	A.R.					
LIOV-(21-38)	18	O/C	-	0.01/sec	CE	-	PN-6	R	Load & Purge	A.R.					Thruster-(21-38)
								R	RCS Engine Burn	E.O.					
								FI	Pc-(21-38) No-Go	A.R.					
LIFV-(21-38)	18	O/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.					Thruster-(21-38)
								R	RCS Engine Burn	E.O.					
								FI	Pc-(21-38) No-Go	A.R.					
VBIV-(21-38)	18	0/28VDC	±20%	-	-	-	EX-1	FI	LBIV-(21-38) No-Go	A.R.					Thruster-(21-38)
VMBV-(21-38)	18	0/28VDC	±20%	-	-	-	EX-1	FI	LMBV-(21-38) No-Go	A.R.					Thruster-(21-38)
VIOV-(21-38)	18	0/28VDC	±20%	-	-	-	EX-1	FI	LIOV-(21-38) No-Go	A.R.					Thruster-(21-38)
VIFV-(21-38)	18	0/28VDC	±20%	-	-	-	EX-1	FI	LIFV-(21-38) No-Go	A.R.					Thruster-(21-38)
VII-(21-38)	18	0/28VDC	±20%	-	-	-	VO-1	R	Launch, Postflight, Secure	A.R.					Thruster-(21-38)
								FI	Ignition Failure	A.R.					
IIE-(21-38)	18	TBD		-	-	-	CU-1	FI	Ignition Failure	A.R.					Thruster-(21-38)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.2 Boost. APS Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoT-2,4,6,8	4	0-50 PSIA	±1.0PSIA	20 PSI/sec	D	GO2	P-1B	M	Purge, System Secure	1/sec					T-(4-7) Blanket
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PoT-3,5,7,9	4	0-2000 PSIA	±10PSIA	1000 PSI/sec	D	GO2	P-7A	C	System Active	1/sec					T-(4-7) Resupply
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfT-2,4,6,8	4	0-50 PSIA	±1.0PSIA	20 PSI/sec	D	GH2	P-1B	M	Purge, System Secure	1/sec					T-(8-11) Blanket
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfT-3,5,7,9	4	0-2000 PSIA	±10 PSIA	1000 PSI/sec	D	GH2	P-7A	C	System Active	1/sec					T-(8-11) Resupply
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PoL-5,8,11,14	4	0-2000 PSIA	±10PSIA	1000 PSI/sec	D	GO2	P-7A	R	Preflight, Postflight	E.O.					F-(6,7,4,5) Resp.
								FI	Leakage Detected	A.R.					
								FI	RCS Feedline PR. No-Go	A.R					
PfL-3,6,9,12	4	0-2000 PSIA	±10PSIA	1000 PSI/sec	D	GH2	P-7A	R	Preflight, Postflight	E.O.					F-(10,11,8,9) Resp.
								FI	Leakage Detected	A.R.					
								FI	RCS Feedline PR. No-Go	A.R.					
PoL-4	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GO2	P-6	M	RCS/Sep. Sys. Active	5/sec					Fwd RCS/Sep. F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	RCS/Sep. Thruster No-Go	A.R.					
PoL-7	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GO2	P-6	M	Sep. System Active	5/sec					AFT Sep F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	Sep. Thruster No-Go	A.R.					
PoL-10	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GO2	P-6	M	RCS/Sep. Sys. Active	5/sec					Fwd RCS/Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	RCS/Sep. Thruster No-Go	A.R.					
PoL-13	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GO2	P-6	M	Sep. System Active	5/sec					Aft Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Sep. Thruster No-Go	A.R.					
PfL-2	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GH2	P-6	M	RCS/Sep. Sys. Active	5/sec					Fwd RCS/Sep F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	RCS/Sep. Thruster No-Go	A.R.					
PfL-5	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GH2	P-6	M	Sep. System Active	5/sec					Aft Sep. F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	Sep. Thruster No-Go	A.R.					

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

A-39 and A-40

(Continued)

SUBSYSTEM: 2.2 Boost. APS Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PfL-8	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GH2	P-6	M	RCS/Sep. Sys. Active	5/sec					Fwd RCS/Sep F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	RCS/Sep. Thruster No-Go	A.R.					
PfL-11	1	0-800 PSIA	±4 PSIA	1000 PSI/sec	D	GH2	P-6	M	Sep. System Active	5/sec					Aft Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Sep. Thruster No-Go	A.R.					
PoL-3	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GO2	P-1A	M	Purge, System Secure	1/sec					Fwd RCS/Sep. F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PoL-6	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GO2	P-1A	M	Purge, System Secure	1/sec					Aft Sep. F/dline, Boom A
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PoL-9	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GO2	P-1A	M	Purge, System Secure	1/sec					Fwd RCS/Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PoL-12	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GO2	P-1A	M	Purge, System Secure	1/sec					Aft Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfL-1	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GH2	P-1A	M	Purge, System Secure	1/sec					Fwd RCS/Sep. F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfL-4	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GH2	P-1A	M	Purge System Secure	1/sec					Aft Sep. F'dline, Boom A
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfL-7	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GH2	P-1A	M	Purge, System Secure	1/sec					Fwd RCS/Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
PfL-10	1	0-50 PSIA	±1 PSIA	20 PSI/sec	D	GH2	P-1A	M	Purge, System Secure	1/sec					Aft Sep. F'dline, Boom B
								R	Load & Purge	A.R.					
								FI	Leakage Detected	A.R.					
ToT-(2-5)	4	0-750° R	±5°R	200°R/sec	D	GO2	T-3	M	APS Sys. Active	1/sec					T-(4,5,7,6) Resp.
								R	Load & Purge	A.R.					
TfT-(2-5)	4	0-750°R	±5°R	200°R/sec	D	GH2	T-3	M	APS Sys. Active	1/sec					T-(8-11) Resp.
								R	Load & Purge	A.R.					
LOPV-(1-8)	8	O/C	-	0.5 sec	CE	-	PN-2A	R	Load & Purge	E.O.					V-(29-36)
								R	System Secure	A.R.					
								FI	Feedline Press. No-Go	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

A-41 and A-42
(Continued)
SUBSYSTEM: 2.2 Boost. APS Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
LFPV-(1-8)	8	O/C	-	0.5 sec	CE	-	PN-2A	R	Load & Purge	E.O.					V-(37-44)
								R	System Secure	A.R.					
								FI	Feedline Press. No-Go	A.R.					
LOFV-2	1	O/C	-	0.5 sec	CE	-	PN-2A	R	GO2 Fill, Purge	E.O.					V-89
								FI	Fill Rate No-Go, or						
									PoT-6,7 No-Go	A.R.					
LFFV-2	1	O/C	-	0.5 sec	CE	-	PN-2A	R	GH2 Fill, Purge	E.O.					V-88
								FI	Fill Rate No-Go, or						
									PfT-4,5 No-Go	A.R.					
LOFC-2	1	O/C	-	-	CE	-	PN-3	R	GO2 Fill, Purge	E.O.					C-8
								FI	Fill Rate No-Go	A.R.					
LFFC-2	1	O/C	-	-	CE	-	PN-3	R	GH2 Fill, Purge	E.O.					C-9
								FI	Fill Rate No-Go	A.R.					
VOPV-(1-8)	8	0/28VDC	±20%	-	-	-	EX-1	FI	LOPV-(1-8) No-Go	A.R.					V-(29-36)
VFPV-(1-8)	8	0/28VDC	±20%	-	-	-	EX-1	FI	LFPV-(1-8) No-Go	A.R.					V-(37-44)
VOFV-2	1	0/28VDC	±20%	-	-	-	EX-1	FI	LOFV-2 No-Go	A.R.					V-89
VFFV-2	1	0/28VDC	±20%	-	-	-	EX-1	FI	LFFV-2 No-Go	A.R.					V-88

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.3 Boost.Hydrogen Cond.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE.		DATA RATE		DIU NO.	REMARKS
Pc-(39-41)	3	0-1000 PSIA	±5 PSIA	50,000 PSI/sec	D	Hot Gas	P-5	C	Subsys. Start & Shutdown	A.R.					G-(1-3)
								M	Subsystem Operating	1/sec					
								FI	PPD-(1-3) No-Go	A.R.					
PPTL-(1-3)	3	0-100 PSIA	±1 PSIA	20 PSI/sec	D	Oil	P-2A	M	Subsystem Operation	1/2 sec					PT-(1-3)
								R	G.G. Prestart	E.O.					
PPD-(1-3)	3	0-2000 PSIA	±10 PSIA	1500 PSI/sec	D	LH2	P-7	M	Subsystem Operating	1/sec					P-(1-3)
								R	Start-Up	E.O.					
								FI	PfL-(13-19) or						
									PHEO-91-3) No-Go	A.R.					
Tc-(1-3)	3	0-2500°R	±20°R	200°R/sec	D	Hot Gas	T-7	M	Subsys. Operating	1/sec					G-(1-3)
								FI	THE-(1-3) No-Go	A.R.					
TPTL-(1-3)	3	0-1300°R	±10°R	20°R/sec	D	Oil	T-5	M	Subsys. Operating	1/2 sec					PT-(1-3)
								FI	PPD-(1-3) No-Go	A.R.					
QPTL-(1-3)	3	0-6"	±.125"	12in./sec	D	Oil	L-2	M	Subsystem Operating	1/2 sec					PT-(1-3)
								R	G.G Start-Up	E.O.					
								FI	PPTL-(1-3) No-Go	A.R.					
NT-(1-3)	3	0-100K RPM	±500	10K RPM/sec	D	-	SP-1	C	Subsys. Start	E.O.					U-(1-3)
								M	Subsys. Operating	2/sec					Record Oper. Time
								FI	PPD-(1-3) No-Go	A.R.					
LGOV-(1I-3I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness CK.	E.O.					GOV-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limit	A.R.					
LGFV-(1I-3I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness CK.	E.O.					GFV-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limit	A.R.					
LGOV-(1-3)	3	O/C	-	0.01 sec	CE	-	PN-6	C	Subsys. Start & Shutdown	E.O.					GOV-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limits	A.R.					
LGFV-(1-3)	3	O/C	-	0.01 sec	CE	-	PN-6	C	Subsys. Start & Shutdown	E.O.					GFV-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limit	A.R.					
LIOV-(39-41)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limit	A.R.					
LIFV-(39-41)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(1-3)
								R	Load & Purge	A.R.					
								FI	Pc-(39-41) Out-Of-Limit	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 2.3 Boost.Hydrogen Cond.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
LFIV-(8-10)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Load, Purge, Pre-Start.	E.O.					V-90,92,94
								FI	PPD-(1-3) No-Go	A.R.					
LPSV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Start & Shutdown	E.O.					V-91,93,63
								R	Load & Purge	A.R.					
								FI	PPD-(1-3) No-Go	A.R.					
LRIV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Load, Purge, Pre-Start	E.O.					V-46,48,50
								FI	PHEO-(1-3) No-Go	A.R.					
LRPV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Resupply Operation	E.O.					V-45,47,49
								R	Load & Purge	A.R.					
								FI	PHEO-(1-3) No-Go	A.R.					
VGOV-(1I-3I)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGOV-(1I-3I) No-Go	A.R.					GOV-(1-3)
VGFV-(1I-3I)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGFV-(1I-3I) No-Go	A.R.					GFV-(1-3)
VGOV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGOV-(1-3) No-Go	A.R.					GOV-(1-3)
VGFV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGFV-(1-3) No-Go	A.R.					GFV-(1-3)
VIOV-(39-41)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LIOV-(39-41) No-Go	A.R.					G-(1-3)
VIFV-(39-41)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LIFV-(39-41) No-Go	A.R.					G-(1-3)
VFIV-(8-10)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LFIV-(8-10) No-Go	A.R.					V-90,92,94
VPSV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LPSV-(1-3) No-Go	A.R.					V-91,93,63
VRIV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LRIV-(1-3) No-Go	A.R.					V-46,48,50
VRPV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LRPV-(1-3) No-Go	A.R.					V-45,47,49
VII-(39-41)	3	0/28VDC	±20%	-	-	-	VO-1	R	Load, Purge, Start	E.O.					G-(1-3)
								FI	Start No-Go	A.R.					
VIEO-(1-3)	3	TBD		-	-	-	VO-2	FI	G.G. Ignition Failure	A.R.					G-(1-3)
IIE-(39-41)	3	TBD		-	-	-	CU-2	FI	G.G. Ignition Failure	A.R.					G-(1-3)
NP-(1-3)	3	0-100K RPM	±500	10K RPM/sec	D	-	SP-1A	FI	PPD-(1-3) Out-Of-Limit	A.R.					P-(1-3)
PPS-(1-3)	3	0-100 PSIA	±1 PSIA	50 PSI/sec	D	LH2	P-2	FI	PPD-(1-3) Out-Of-Limit	A.R.					P-(1-3)
PHEO-(1-3)	3	0-2000 PSIA	±10 PSIA	1500 PSI/sec	D	GH2	P-7	FI	GH2 Resupply No-Go	A.R.					H-(1-3)
								M	GH2 Resupply	1/2 sec					
PCV-(1-3)	3	0-2000 PSIA	±10 PSIA	1500 PSI/sec	D	GH2	P-7	FI	GH2 Resupply No-Go or						V-(51-53)
									Leakage Detector	A.R.					
AT-(1-3)	3	0-5g	±.05g	0-5 KHZ	CE	-	V-1	T,FI	Subsystem Operation	E.O.					U-(1-3)
AP-(1-3)	3	0-5g	±0.5g	0-5KHZ	CE	-	V-1	T,FI	Subsystem Operation	E.O.					P-(1-3)
TPB-(1-3)	3	30-1000°R	±10°R	20°R/sec	D	LH2	T-4	FI	PPD-(1-3) No-Go	A.R.					P-(1-3)
								T	Subsystem Operation	1/2 sec					
THE-(1-3)	3	400-750°R	±5°R	200°R/sec	D	GH2	T-3	M	Resupply Operation	1/2 sec					H-(1-3)
								FI	PHEO-(1-3) Out-Of-Limit	A.R.					

FOLDOUT FRAME

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.4 Boost. Oxygen Cond.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PTI-(1-3)	3	0-100 PSIA	±1.0 PSIA	50 PSI/sec	D	G02	P-2	FI	PTD-(1-3) Out-Of-Limit	A.R.					GU-(1-3)
PTD-(1-3)	3	0-2000 PSIA	±10 PSIA	1500 PSI/sec	D	G02	P-7	M	G02 Resupply	1/sec					CU-(1-3)
								R	Start-Up	E.O					
								FI	PoT-7,9 No-Go	A.R.					
PPTL-(4-6)	3	0-100 PSIG	±1 PSIG	20 PSI/sec	D	Oil	P-2A	M	G02 Resupply	1/2 sec					PT-(4-6)
								R	G.G. Prestart	E.O.					
Pc -(42-44)	3	0-1000 PSIA	±5 PSIA	50,000 PSI/sec	D	Hot Gas	P-5	C	Subsys. Start & Shutdown	A.R.					G-(4-6)
								M	G02 Resupply	1/sec					
								FI	PTD-(1-3) Out-Of-Limit	A.R.					
TPTL-(4-6)	3	0-1300°R	±10°R	20°R/sec	D	Oil	T-5	M	G02 Resupply	1/2 sec					PT-(4-6)
								FI	PTD-(1-3) No-Go	A.R.					
Tc-(4-6)	3	0-2500°R	±20°R	200°R/sec	D	Hot Gas	T-7	M	G02 Resupply	1/sec					G-(4-6)
								FI	PTD-(1-3) No-Go	A.R.					
QPTL-(4-6)	3	0-6 inch	±.125"	12 in./sec	D	Oil	L-2	M	G02 Resupply	1/2 sec					PT-(4-6)
								R	G.G. Prestart	E.O.					
								FI	PPTL-(4-6) No-Go	A.R.					
NT-(4-6)	3	0-100K RPM	±500	10K RPM/sec	D	-	SP-1	C	G.G. Start	E.O.					U-(4-6)
								M	G02 Resupply	2/sec					Record Oper. Time
								FI	PTD-(1-3) No-Go	A.R.					
LGOV-(4I-6I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness CK.	E.O.					GOV-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No-Go	A.R.					
LGOV-(4-6)	3	O/C	-	0.01 sec	CE	-	PN-6	C	Subsys. Start & Shutdown	E.O.					GOV-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No-Go	A.R.					
LGFV-(4I-6I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness CK.	E.O.					GFV-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No.Go	A.R.					
LGFV-(4-6)	3	O/C	-	0.01 sec	CE	-	PN-6	C	Subsys. Start & Shutdown	E.O.					GFV-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No-Go	A.R.					
LOIV-(3-5)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Load, Purge, Pre-Start	E.O.					V-57,59,61
								FI	PTD-(1-3) No-Go	A.R.					
LTSV-(1-3)	3	O/C	-	0,1 sec	CE	-	PN-5	R	Subsys. Start & Shutdown	E.O.					V-58,60,62
								R	Load & Purge	A.R.					
								FI	PTD-(1-3) No-Go	A.R.					

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.4 Boost.Oxygen Cond.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
LIOV-(42-44)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No-Go	A.R.					
LIFV-(42-44)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(4-6)
								R	Load & Purge	A.R.					
								FI	Pc-(42-44) No-Go	A.R.					
VGOV-(4I-6I)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGOV-(4I-6I) No-Go	A.R.					GOV-(4-6)
VGOV-(4-6)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGOV-(4-6) No-Go	A.R.					GOV-(4-6)
VGFV-(4I-6I)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGFV-(4I-6I) No-Go	A.R.					GFV-(4-6)
VGFV-(4-6)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LGFV-(4-6) No-Go	A.R.					GFV-(4-6)
VOIV-(3-5)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LOIV-(3-5) No-Go	A.R.					V-57,59,61
VTSV-(1-3)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LTSV-(1-3) No Go	A.R.					V-58,60,62
VIOV-(42-44)	3	0/s8VDC	±20%	-	-	-	EX-1	FI	LIOV-(42-44) No-Go	A.R.					G-(4-6)
VIFV-(42-44)	3	0/28VDC	±20%	-	-	-	EX-1	FI	LIFV-(42-44) No-Go	A.R.					G-(4-6)
VII-(42-44)	3	0/28VDC	±20%	-	-	-	VO-1	R	Load, Purge, Start	E.O.					G-(4-6)
								FI	Start No-Go	A.R.					
VIEO-(4-6)	3	TBD		-	-	-	VO-2	FI	G.G. Ignition Failure	A.R.					G-(4-6)
IIE-(42-44)	3	TBD		-	-	-	CU-2	FI	G.G. Ignition Failure	A.R.					G-(4-6)
NTC-(1-3)	3	0-300K RPM	±1500	10K RPM/sec	D	-	SP-2	FI	PTD-(1-3) Out-Of-Limit	A.R.					CU-(1-3)
TCB-(1-3)	3	0-2000°R	±20°R	20°R/sec	D	G02	T-6	FI	PTD-(1-3) Out-Of-Limit	A.R.					CU-(1-3)
								T	Resupply Operation	1/2 sec					
PCV-(4-6)	3	0-2000 PSIA	±10 PSIA	1500 PSI/sec	D	G02	P-7	FI	G02 Resupply No-Go, or						V-(85-87)
									Leakage Detected	A.R.					
AT-(4-6)	3	0-5g	±0.5g	0-5 KHZ	CE	-	V-1	T,FI	G02 Resupply	E.O.					U-(4-6)
ATC-(1-3)	3	0-5g	±0.5g	0-5 KHZ	CE	-	V-1	T,FI	G02 Resupply	E.O.					CU-(1-3)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.5 Boost. APS Sep. Engine

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
Pc-(1-20)	20	0-750 PSIA	±5 PSIA	50,000 PSI/sec	D	Hot Gas	P-4	C	Sep. Engine Start	A.R.					Thruster-(1-20)
								M	Sep. Engine Burn	20/sec					
								FI	Sep. Engine No-Go	A.R.					
LBIV-(1-20)	20	O/C	-	0.5 sec	CE	-	PN-2A	R	Load, Purge, Launch, Secure	A.R.					Thruster-(1-20)
								FI	Pc-(1-20) No-Go	A.R.					
LMBV-(1-20)	20	O/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.					Thruster-(1-20)
								R	Sep. Engine Burn	E.O.					
								FI	Pc-(1-20) No-Go	A.R.					
LIOV-(1-20)	20	O/C	-	0.01	CE	-	PN-6	R	Load & Purge	A.R.					Thruster-(1-20)
								R	Sep. Engine Burn	E.O.					
								FI	Pc-(1-20) No-Go	A.R.					
LIFV-(1-20)	20	O/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.					Thruster-(1-20)
								R	Sep. Engine Burn	E.O.					
								FI	Pc-(1-20) No-Go	A.R.					
VBIV-(1-20)	20	0/28VDC	±20%	-	-	-	EX-1	FI	LBIV-(1-20) No-Go	A.R.					Thruster-(1-20)
VMBV-(1-20)	20	0/28VDC	±20%	-	-	-	EX-1	FI	LMBV-(1-20) No-Go	A.R.					Thruster-(1-20)
VIOV-(1-20)	20	0/28VDC	±20%	-	-	-	EX-1	FI	LIOV-(1-20) No-Go	A.R.					Thruster-(1-20)
VIFV-(1-20)	20	0/28VDC	±20%	-	-	-	EX-1	FI	LIFV-(1-20) No-Go	A.R.					Thruster-(1-20)
VII-(1-20)	20	0/28VDC	±20%	-	-	-	VO-1	R	Launch, Postflight, Secure	A.R.					Thruster-(1-20)
								FI	Ignition Failure	A.R.					
IIE-(1-20)	20	TBD	-	-	-	-	CU-1	FI	Ignition Failure	A.R.					Thruster-(1-20)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 2.6 Boost. APS AUX. PWR. Unit

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
Pc-(45-47)	3	0-1000 PSIA	$\pm$5 PSIA	50,000 PSI/sec	D	Hot Gas	P-5	C	APU Start & Shutdown	A.R.					G-(7-9)
								M	APU Operation	1/sec					
								FI	NT-(7-9) Out-Of-Limit	A.R.					
PPTL-(7-9)	3	0-100 PSIG	$\pm$1 PSIG	20 PSI/sec	D	Oil	P-2A	M	APU Operation	1/2 sec					PT-(7-9)
								R	G.G. Prestart	E.O.					
TPTL-(7-9)	3	0-1300^{o}R	$\pm$10^{o}R	20^{o}R/sec	D	Oil	T-5	M	APU Operation	1/2 sec					PT-(7-9)
								FI	NT-(7-9) Out-Of-Limits	A.R.					
QPTL-(7-9)	3	0-6"	$\pm$.125"	12 in./sec	D	Oil	L-2	M	APU Operation	1/2 sec					PT-(7-9)
								R	G.G. Start-Up	E.O.					
								FI	PPTL-(7-9) No-Go	A.R.					
NT-(7-9)	3	0-100K RPM	$\pm$500	10K RPM/sec	D	-	SP-1	C	G.G. Start	E.O.					X-(1-3)
								M	APU Operating	2/sec					
								FI	NS-(1-3) Out-Of-Limit	A.R.					
LIOV-(45-47)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
LIFV-(45-47)	3	O/C	-	0.01/sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					G-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
LGOV-(7-9)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					GOV-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
LGFV-(7-9)	3	O/C	-	0.01 sec	CE	-	PN-6	C	G.G. Start & Shutdown	E.O.					GFV-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
LGOV-(7I-9I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness Ck.	E.O.					GOV-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
LGFV-(7I-9I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsys. Readiness Ck.	E.O.					GFV-(7-9)
								R	Load & Purge	A.R.					
								FI	Pc-(45-47) No-Go	A.R.					
VIOV-(45-47)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LIOV-(45-47) No-Go	A.R.					G-(7-9)
VIFV-(45-47)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LIFV-(45-47) No-Go	A.R.					G-(7-9)
VGOV-(7-9)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LGOV-(7-9) No-Go	A.R.					GOV-(7-9)
VGFV-(7-9)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LGFV-(7-9) No-Go	A.R.					GFV-(7-9)
VGOV-(7I-9I)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LGOV-(7I-9I) No-Go	A.R.					GOV-(7-9)
VGFV-(7I-9I)	3	0/28VDC	$\pm$20%	-	-	-	EX-1	FI	LGFV-(7I-9I) No-Go	A.R.					GFV-(7-9)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 2.6 Boost. APS AUX. PWR. Unit

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
VII-(45-47)	3	0-28VDC	±20%	-	-	-	VO-1	R	Load, Purge, Start	E.O.					G-(7-9)
								FI	Start No-Go	A.R.					
VIEO-(7-9)	3	TBD	-	-	-	-	VO-2	FI	G.G. Ignition Failure	A.R.					G-(7-9)
IIE-(45-47)	3	TBD		-	-	-	CU-2	FI	G.G. Ignition Failure	A.R.					G-(7-9)
Tc-(7-9)	3	0-2500°R	±20°R	200°R/sec	D	Hot Gas	T-7	M	APU Operating	1/sec					G-(7-9)
								FI	NT-(7-9) No-Go	A.R.					
AT-(7-9)	3	0-5g	±0.5g	0-5 KHZ	CE	-	V-1	T,FI	APU Operation	E.O.					X-(1-3)
NS-(1-3)	3	0-100K RPM	±500	10K RPM/sec	D	-	SP-1	FI	APU No-Go	A.R.					PT-(7-9)

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

A-57 and A-58

SUBSYSTEM: 3.1, 6.1, Airbreathing Engine

IDENTITY CODE	* QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PfCCI	1	0-60 psia	±.5 psi	20 psi/sec	D	GH_2	P-1-TF	FI	Engine Malfunction	A.R.				Eng. Cont.	
PLPD	1	0-100 psia	±.5 psi	20 psi/sec	D	Lube	P-2A-TF	M	Engine Active	5/sec				Eng. Cont.	
								R	Engine Startup	A.R.					
								FI	Engine Malfunction	A.R.					
PSPD	1	0-100 psia	±.5 psi	20 psi/sec	D	Lube	P-2A-TF	M	Engine Active	5/sec				Eng. Cont.	
								R	Engine Startup	A.R.					
								FI	Engine Malfunction	A.R.					
PG	1	0-100 psia	±.5 psi	20 psi/sec	D	Lube	P-2A-TF	M	Engine Active	5/sec				Eng. Cont.	
								FI	Engine Malfunction	A.R.					
PFI	1	0-20 psia	±.5 psi	20 psi/sec	D	Air	P-1C-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
PHPT	1	0-200 psia	± 5 psi	20 psi/sec	D	Hot Gas	P-3A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
PED	1	0-150 psia	± 2 psi	20 psi/sec	D	Hot Gas	P-3B-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
PDVDVP	1	0-200 psia	± 4 psi	20 psi/sec	D	LH_2	P-3C-TF	C*	Engine Active	100/sec				Eng. Cont	*Gas Path Analysis
								R	Engine Startup	A.R.					
								FI	Engine Malfunction	A.R.					
TfCCI	1	0-600°R	± 10°R	20°/sec	D	GH_2	T-2-TF	FI	Engine Malfunction	A.R.				Eng. Cont.	
TSPD	1	0-1000°F	± 20°F	20°/sec	D	Lube	T-5A-TF	M	Engine Active	5/sec				Eng. Cont.	
								R	Engine Startup	A.R.					
								FI	Engine Malfunction	A.R.					
TIA	1	0-1000°R	± 20°R	20°/sec	D	Air	T-4A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
THPT	1	0-2500°R	± 40°R	20°/sec	D	Hot Gas	T-7A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
TLPTD	1	0-2500°R	± 40°R	20°/sec	D	Hot Gas	T-7A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
TED	1	0-2500°R	± 40°R	20°/sec	D	Hot Gas	T-7A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
TCI	1	0-2500°R	± 20°R	20°/sec	D	Hot Gas	T-7A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
TTB	1	0-1500°R	± 20°R	20°/sec	D	Hot Gas	T-5B-TF	M	Engine Active	25/sec				Eng. Cont.	
								R	Engine Start/Shutdown	A.R.					
TFH	1	0-600°R	± 10°R	20°/sec	D	GH_2	T-2-TF	FI	Engine Active	A.R.				Eng. Cont.	
FfF	1	0-20 lb/sec	±.5 lb/s	15 lb/sec^2	D	GH_2	FR-1A-TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
								R	Engine Start-Stop	A.R.					
QLO	1	0-1 ft	±.03 ft	20 ft/sec	D	Oil	L-2A-TF	M	Engine Active	5/sec				Eng. Cont.	
								R	Engine Start-Stop	A.R.					
NHPT	1	0-15000 rpm	± 50 rpm	5000 rpm/sec	CE	-	SP-3-TF	C*	Engine Active	100/sec				Eng. Cont	*Gas Path Analysis
NF	1	0-15000 rpm	± 50 rpm	1000 rpm/sec	CE	-	SP-3TF	C*	Engine Active	100/sec				Eng. Cont.	*Gas Path Analysis
NVDVP	1	0-20000 rpm	± 50 rpm	1000 rpm/sec	CE	-	SP-3-TF	M	Engine Active	10/sec				Eng. Cont.	
								R	Engine Start-Stop						
AFFB	1	0-5 g	±0.5 g	0-3000 HZ	CE	-	V-1A-TF	T	Engine Active	TBD				Eng. Cont.	
AFCB	1	0-5 g	±0.5 g	0-3000 HZ	CE	-	V-1A-TF	T	Engine Active	TBD				Eng. Cont.	

*Per Engine

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

(Continued)
SUBSYSTEM: 3.1, 6.1, Airbreathing Engine

IDENTITY CODE	QTY.*	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
ALPRB	1	0-5 g	±0.5 g	0-3000 HZ	CE	-	V-1A-TF	T	Engine Active					Eng. Cont.	
LFIVA/B	1	O/C	-	0.1 sec	CE	-	PN-5-TF	C	Engine Start/Shutdown	A.R.				Eng. Cont.	
LSDV	1	O/C	-	0.1 sec	CE	-	PN-5-TF	C	Engine Start/Shutdown	A.R.				Eng. Cont.	
VFIVA/B	1	0/28 V	-	-	-	-	EX-1-TF	FI	Apparent Valve Failure	A.R.				Eng. Cont.	
VSDV	1	0/28 V	-	-	-	-	EX-1-TF	FI	Apparent Valve Failure	A.R.				Eng. Cont.	
VC	1	0/28 V	-	-	-	-	EX-1A-TF	FI	Engine Malfunction	A.R.				Eng. Cont.	
VIIA/B	1	0/28 V	-	-	-	-	VO-1-TF	FI	Ignition Failure	A.R.				Eng. Cont.	
								R	Engine Start	A.R.				Eng. Cont.	
VIEO	1	TBD	-	-	-	-	VO-2-TF	FI	Ignition Failure	A.R.				Eng. Cont.	
VFH	1	0/28 V	-	-	-	-	VO-3-TF	M	Engine Active	10/sec				Eng. Cont.	
								R	Engine Start-Stop						
								FI	Engine Malfunction	A.R.					
III	1	TBD	-	-	-	-	CU-3-TF	FI	Ignition Failure	A.R.				Eng. Cont.	
								R	Engine Start	A.R.					
IFH	1	TBD	-	-	-	-	CU-4-TF	M	Engine Active	1/sec				Eng. Cont.	
								FI	Heater Malfunction	A.R.					
								R	Engine Start	A.R.					
FLB	1	on/off	-	0.1 sec	D	Hot Gas	FL-1-TF	C	Engine Start	A.R.					
								M	Engine Shutdown	10/sec					
ACEC	1	30 to 160 db	± 2 db	50 HZ to 10KHZ	D		AC-1-TF	T	Engine Active	TBD				Eng. Cont.	
LCPRV	1	O/C	-	0.1 sec	CE		PN-5-TF	R	Engine Start	A.R.				Eng. Cont.	
PZGL	1	0-100 psia	±.5 psi	20 psi/sec	D	Lube	P-2A-TF	R	Zero G Engine Lube P	A.R.				Eng. Cont.	
VCPRV	1	0/28VDC	±20%	-	-	-	EX-1-TF	FI	LCPRV No-Go	A.R.				Eng. Cont.	

*Per Engine

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 3.2 Boost. A/B Prop. Mgmt.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PfT-10	2	0-60 PSIA	±2 PSIA	20 PSI/sec	D	LH2	P-1	R	Load & Purge	E.O.					T-12 A & B
								M	A/B Sys. Active	1/sec					
								FI	FF-1 Out-Of-Limit	A.R.					
PfL-(13-19)	7	0-60 PSIA	±2 PSIA	20 PSI/sec	D	LH2	P-1	R	Load & Purge	E.O.					Turbofan Inlet
								C	TF Start & Shutdown	A.R.					
								M	TF Operation	5/sec					
								FI	Low TF Thrust	A.R.					
TfT-6	2	0-100°R	±5°R	10°R/sec	D	LH2	T-1	R	Load & Purge	E.O.					T-12 A & B
								M	A/B Sys. Active	1/sec					
								FI	FF-1 Out-Of-Limit	A.R.					
TfL-(1-7)	7	0-100°R	±5°R	10°R/sec	D	LH2	T-1	R	Load & Purge	E.O.					Turbofan Inlet
								C	TF Start & Shutdown	A.R.					
								M	TF Operation	5/sec					
								FI	Low TF Thrust	A.R.					
QfT-(4-6)	6	0-20 Ft.	±.07 ft.	100 ft/sec	D	LH2	L-3	R	Load & Purge	E.O.					T-12 A & B (Vertical)
								C	LH2 Fill	10/sec					
								FI	Improper Fill Rate	A.R.					
QfT-(7-9)	6	0-20 ft	±.07 ft	100 ft/sec	D	LH2	L-3	R	Load & Purge	E.O.					T-12 A & B (Horiz.)
								M	A/B sys. Active	10/sec					
								FI	A/B No-Go	A.R.					
LFDV-(1-4)	8	O/C	-	0.3 sec	CE	-	PN-2	R	Load & Purge	E.O.					V-84,98,99,100 A & B
								FI	FF-1 No-Go	A.R.					
LFFV-3	2	O/C	-	0.4 sec	CE	-	PN-2A	R	Load & Purge	E.O.					V-74 A & B
								FI	Cruise T. Fill No-Go	A.R.					
LFVV-(5-8)	8	O/C	-	0.3 sec	CE	-	PN-2	R	Load & Purge	E.O.					V-(70-73) A & B
								FI	PfT-10 Out-Of-Limit	A.R.					
LEFV-(1-28)	28	O/C	-	0.2 sec	CE	-	PN-4	R	Load & Purge	E.O.					EFV-(1-28)
								R	TF Start & Shutdown	E.O.					
								FI	PfL-(13-19) No-Go	A.R.					
VFDV-(1-4)	8	0/28VDC	±20%	-	-	-	EX-1	FI	LFDV-(1-4) No-Go	A.R.					V-84,98,99,100 A & B
VFFV-3	2	0/28VDC	±20%	-	-	-	EX-1	FI	LFFV-3 No-Go	A.R.					V-74 A & B
VFVV-(5-8)	8	0/28VDC	+20%	-	-	-	EX-1	FI	LFVV-(5-8) No-Go	A.R.					V-(70-73) A & B
VEFV-(1-28)	28	0/28VDC	+20%	-	-	-	EX-1	FI	LEFV-(1-28) No-Go	A.R.					EFV-(1-28)
LFVC-2	2	O/C	-	-	CE	-	PN-3	R	Load & Purge	E.O.					C-10
								FI	PfT-10 Out-Of-Limits	A.R.					
FF-1	2	0-20 lb/sec	±0.25	100 lb/sec^2	D	LH2	FR-1	M	A/B Sys. Active	1/sec					Fuel Distr. Line
								FI	PPS-(1-3) Out-Of-Limit	A.R.					

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 3.3 Boost A/B Press.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PfL-20	2	0-2000 PSIA	±10 PSIA	500 PSI/sec	D	GH2	P-7B	R	Load & Purge	E.O.					F-12 A & B
								FI	Leakage Detected	A.R.					
								FI	PfT-10 No-Go	A.R.					
LFPV-9,10	4	O/C	-	0.3 sec	CE	-	PN-2	R	Load & Purge	E.O.					V-75,76 A & B
								FI	PfT-10 No-Go	A.R.					
VFPV-9,10	4	0/28VDC	±20%	-	-	-	EX-1	FI	LFPV-9,10 No-Go	A.R.					V-75,76 A & B

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.2, ORB. MAIN PROP. MGMT.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoT-1,2	2	0-50 psia	± 2 psi	20 psi/sec	D	GO_2,GH*	P-1	C	LO_2 Load Pressurization	10/sec				18,19,20	*LO_2 Tank Ullage
								C	Main Engine Burn	1/sec					
								R	Load & Purge	A.R.					
								M	Purge & Blanket Press.	Negl.					
PoL-1,3	2	0-100 psia	± 5 psi	20 psi/sec	D	LO_2	P-2	FI	Low Main Engine Thrust	A.R.				18,19,20	
								R	Load & Purge	A.R.					
PoF-1	1	0-100 psia	± 5 psi	20 psi/sec	D	LO_2	P-2	R	LO_2 Load, Start	A.R.				15,16,17	
								FI	Slow LO_2 Tank Fill	A.R.					
PfT-1	1	0-50 psia	± 2 psi	20 psi/sec	D	LH_2, HE*	P-1	C	LH_2 Load Pressurization	10/sec				18,19,20	*LH_2 Tank Ullage
								C	Main Engine Burn	1/sec					
								M	Purge & Blanket Press.	Negl.					
								R	Load & Purge	A.R.					
PfL-2,3	2	0-100 psia	± 5 psi	20 psi/sec	D	LH_2	P-2	R	Load & Purge	A.R.				18,19,20	
								FI	Low Main Engine Thrust	A.R.					
PfF-1	1	0-100 psia	± 5 psi	20 psi/sec	D	LH_2	P-2	R	LH_2 Load, Start	A.R.				18,19,20	
								FI	Slow LH_2 Tank Fill	A.R.					
ToT-1,2	2	0 -700°R	± 5°R	20°/sec	D	GO_2,HE*	T-2	R	Load & Purge	A.R.				18,19,20	*LO_2 Tank Ullage
								FI	PoT-1, or 2 out of limit	A.R.					
								M	System Active	1/sec					
ToL-1,3	2	0-700°R	± 5°R	20°/sec	D	LO_2	T-2	R	Load & Purge	A.R.				18,19,20	
								FI	PoL-1 or 3 out of limit	A.R.					
TfT-1	1	0-700°R	± 5°R	20°/sec	D	GH_2*	T-2	M	System in use	1/sec				18,19,20	*LH_2 Tank Ullage
								FI	PfT-1 out of limit	A.R.					
								R	Load	A.R.					
TfL-2,3	2	0-700°R	± 5°R	20°/sec	D	LH_2	T-2	FI	PfL-2 or 3 out of limit	A.R.				18,19,20	
								R	Load & Purge	A.R.					
QoT-1,4	2	C/U	± .13"	.001 sec	D	LO_2	L-1	C	LO_2 Load	10/sec				18,19,20	
								C	Main Engine Burn*	10/sec					*After QoT-2,5 Uncover
QoT-2,5	2	C/U	± .13"	.001 sec	D	LO_2	L-1	C	LO_2 Load*	10/sec				18,19,20	*After QoT-1,4 Covered
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					
QoT-3,6	2	C/U	± .13"	.001 sec	D	LO_2	L-1	C	LO_2 Load*	10/sec				18,19,20	*After QoT-2,5 Covered
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					
QfT-1	1	C/U	± .13"	.001 sec	D	LH_2	L-1	C	LH_2 Load	10/sec				18,19,20	
								C	Main Engine Burn*	10/sec					*After QfT-2 Uncover
								R	Load	A.R.					

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.2, ORB, MAIN PROP. MGMT.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
QfT-2	1	C/U	± .13"	.001 sec	D	LH_2	L-1	C	LH_2 Load*	10/sec				18,19,20	*After QfT-1 Covered
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					
QfT-3	1	C/U	± .13"	.001 sec	D	LH_2	L-1	C	LH_2 Load*	10/sec				18,19,20	*After QfT-2 Covered
								C	Main Engine Burn	10/sec					
								R	Load	A.R.					
LOIV-1,2	2	0/C	-	0.5 sec	CE	-	PN-2A	R	Per POS. Status List	A.R.				18,19,20	
								FI	Low Main Eng. Thrust	A.R.					
								T	In-Flight Secure	50/sec					
LOVV-(1-4)	4	0/C	-	0.3 sec	CE	-	PN-2	R	LO_2 Load & Purge	E.O.				18,19,20	
								FI	PoT-1 or 2 out of limit	A.R.					
LOFV-1	1	0/C	-	0.5 sec	CE	-	PN-2A	R	LO_2 Load & Purge	A.R.				15,16,17	
LFIV-1,2	2	0/C	-	0.5 sec	CE	-	PN-2A	R	Per POS. Status List	A.R.				18, 19,20	
								FI	Low Main Eng. Thrust	A.R.					
								T	In-Flight Secure	50/sec					
LFTVV-(1-4)	4	0/C	-	0.3 sec	CE	-	PN-2	R	LH_2 Load & Purge	A.R.				15,16,17	
								FI	PfT-1 out of limit	A.R.					
LFFV-1	1	0/C	-	0.5 sec	CE	-	PN-2A	R	LH_2 Load & Purge	A.R.				15,16,17	
LOFC-1	1	0/C	-	-	CE	-	PN-3	R	LO_2 Load & Purge	A.R.				15,16,17	
LHC-1,2	2	0/C	-	-	CE	-	PN-3	R	LH_2 Load & Purge	A.R.				15,16,17	
LFTVC-1	1	0/C	-	-	CE	-	PN-3	R	LH_2 Load & Purge	A.R.				15,16,17	
LFFC-1	1	0/C	-	-	CE	-	PN-3	R	LH_2 Load & Purge	A.R.				15,16,17	
LHC-7,8	2	0/C	-	-	CE	-	PN-3	R	LH_2 Load & Purge	A.R.				15,16,17	
VOIV-1,2	2	0/28 VDC	± 20%	-	-	-	EX-1	FI	LOIV-1 or 2 no-go	A.R.				18,19,20	
VOVV-(1-4)	4	0/28 VDC	± 20%	-	-	-	EX-1	FI	LOVV-(1-4) no-go	A.R.				18,19,20	
VOFV-1	1	0/28 VDC	± 20%	-	-	-	EX-1	FI	LOFV-1 no-go	A.R.				15,16,17	
VFIV-1,2	2	0/28 VDC	± 20%	-	-	-	EX-1	FI	LFIV-1,2 no-go	A.R.				18,19,20	
VFTVV-(1-4)	4	0/28 VDC	± 20%	-	-	-	EX-1	FI	LFTVV-(1-4) no-go	A.R.				15,16,17	
VFFV-1	1	0/28 VDC	± 20%	-	-	-	EX-1	FI	LFFV-1 no-go	A.R.				15,16,17	
PgRL-1	1	0-200 psia	± 2psi	20 psi/sec	D	LO_2,HE	P-3	M	LO_2 Load	1/sec				15,16,17	
								R	Load & Purge	A.R.					
PoS-1,2	2	0-2000 psia	± 2 psi	20 psi/sec	D	LO_2	P-3	M	Boost	20/sec					
								R	Load & Purge	A.R.					
								FI	Low LO_2 Pres.	A.R.					
PfS-1,2	2	0-100 psia	± 2 psi	20 psi/sec	D	LH_2	P-2	M	Boost	20/sec					
								R	Load & Purge	A.R.					
								FI	Low LH_2	A.R.					

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 4.2, ORB. MAIN PROP. MGMT.

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
ToS-1,2	2	0-600°R	± 5°	20°/sec	D	LO_2	T-2	R	Load & Purge	A.R.				Eng. Cont.	
								M	Engine Active	1/sec.					
								FI	Engine Supply Wrong	A.R.					
TfS-1,2	2	0-600°R	± 5°	20°/sec	D	LH_2	T-2	R	Load & Purge	A.R.				Eng. Cont.	
								FI	Engine Supply Wrong	A.R.					
								M	Engine Active	1/sec					

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.3, Main Pressurization Subsyste

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PgO-1,2,3	3	0-1200 psia	± 10 psi	500 psi/sec	D	GO_2	P-6A	R	Main Eng. Start/Burn,Ready	A.R.				15,16,17	Autogenous System
								FI	Ullage Pres. Low	A.R.					
PgF-1,2,3,	3	0-1200 psia	± 10 psi	500 psi/sec	D	GH_2	P-6A	R	Main Eng. Start/Burn,Ready	A.R.				15,16,17	Autogenous System
								FI	Ullage Pres. Low	A.R.					
LOPCV-1,2	2	O/C		0.5 sec	CE	GO_2	PN-2A	R	Main Tank Pressurization	E.O.				15,16,17	
								FI	Ullage Pres. Low	A.R.					
LFPCV-1,2	2	O/C		0.5 sec	CE	GH_2	PN-2A	R	Main Tank Pres.	E.O.				15,16,17	
								FI	Ullage Press. Low	A.R.					
LHC-3,4	2	O/C		0.5 sec	CE	HE	PN-2A	R	Load LH	E.O.				15,16,17	
LHC-5,6	2	O/C		0.5 sec	CE	HE	PN-2A	R	Load LO_2	E.O.				15,16,17	
VOPCV-1,2	2	0/28 V	± 20%				EX-1	FI	LOPCV-1,2 Apparent Fail.	A.R.				15,16,17	
VFPCV-1,2	2	0/28 V	± 20%				EX-1	FI	LFPCV-1,2 Apparent Fail.	A.R.				15,16,17	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.4 On-Orbit Propellant Subsystem

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoT-3	1	0-50 psia	± 2 psi	20 psi/sec	D	GO_2	P-1	M	Ferry, On-Orbit, Boost	1/sec				18,19,20	
								C	Off-Orbit Vent	E.O.					
								M	Load LO_2	10/sec					
								R	Load & Purge	A.R.					
								FI	Reg. or Filter Fail.	A.R.					Verify Upstream Press.
PfT-2,3	2	0-50 psia	± 2 psi	20 psi/sec	D	GH_2	P-1	M	Ferry, On-orbit, Boost	1/sec				18,19,20	
								C	Off-orbit Vent	E.O.					
								R	Load & Purg	A.R.					
								M	Load LH_2	10/sec					
								FI	Reg. or Filter Fail.	A.R.					Verify Upstream Press.
ToT-3	1	0-700°R	± 5°R	20°R/sec	D	GO_2	T-2	R	Load & Purge	A.R.				18,19,20	
								M	(See PoT-3)						
TfT-2,3	2	0-700°R	± 5°R	20°R/sec	D	GH_2	T-2	M	(See PfT-2,3)					18,19,20	
								R	Load & Purge	A.R.					
QoT-(7-9)	3	C/U	± .13"	.001"/sec	D	LO_2	L-1	C	Load and Boost	10/sec				18,19,20	
								R	Load & Purge	A.R.					
QfT-(4-9)	6	C/U	± .13"	.001"/sec	D	LH_2	L-1	C	Load and Boost	10/sec				18,19,20	
								R	Load & Purge	A.R.					
LOTVV-1,2	2	O/C	-	0.3 sec	CE	GO_2	PN-2	R	Load, Boost, Purge	A.R.				18,19,20	
LFTVV-(5-8)	4	O/C	-	0.3 sec	CE	GH_2	PN-2	R	Load, Boost, Purge	A.R.				18,19,20	
LOIV-3	1	O/C	-	0.5 sec	CE	LO_2	PN-2A	R	Ferry, On-Orbit, Boost	E.O.				18,19,20	
								FI	Low O_2 Supply Press.	A.R.					
LFIV-3,4	2	O/C	-	0.5 sec	CE	LH_2	PN-2A	R	Ferry, On-orbit, Boost	E.O.				18,19,20	
								FI	Low H_2 Supply Press.	A.R.					
LFVC-1	1	O/C	-	0.3 sec	CE	GH_2		R	Load	A.R.				15,16,17	
VOTVV-1,2	2	0/28 V	± 20%				EX-1	FI	LOTVV-1,2 Apparent Fail.	A.R.				18,19,20	
VFTVV-(5-8)	4	0/28 V	± 20%				EX-1	FI	LFTVV-(5,8) Apparent Fail.	A.R.				18,19,20	
VOIV-3	1	0/28 V	± 20%				EX-1	FI	LOIV-3 Apparent Fail.	A.R.				18,19,20	
VFIV-3,4	2	0/28 V	± 20%				EX-1	FI	LFIV-3,4 Apparent Fail.	A.R.				15,16,17	
ToL-2	1	0-700°R	± 5°R	20°R/sec	D	LO_2	T-2	M	Load, Boost	2/sec				18,19,20	
								R	Load & Purge	A.R.					
PoL-2	1	0-50 psia	± 2 psi	20 psi/sec	D	LO_2	P-1	M	Load, Boost	2/sec				18,19,20	
								R	Load & Purge	A.R.					
TfL-1, 4	2	0-700°R	± 5°R	20°R/sec	D	LH_2	T-2	M	Load, Boost	2/sec				18,19,20	
								R	Load & Purge	A.R.					
PfL-1,4	2	0-50 psia	± 2 psi	20 psi/sec		LH_2	P-1	M	Load, Boost	2/sec				18,19,20	
								R	Load & Purge	A.R.					

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.4 On-Orbit Prop. Mgmt. (Cont.)

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
ToL-4	1	0-700 deg. R	±5 °R	20/sec	D	LO_2	T-2	M	Ferry, On-Orbit, Boost	1/sec				18,19,20	
								R	Load & Purge	A.R.					

A-77 and A-78

TABLE A-1 (Cont.)
OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 4.5 On-Orbit Pressurization Subsystem

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
Pol-10	1	0-200 psia	± 10 psi	500 psi/sec	D	GO_2	P-7B	FI	Low O_2 Pressure	A.R.				18,19,20	
								R	Load & Purge	A.R.					
PfL-14	1	0-200 psia	± 10 psi	500 psi/sec	D	GH_2	P-7B	FI	Low H_2 Pressure	A.R.				18,19,20	
								R	Load & Purge	A.R.					
VFPV-(1,2)	2	0/28 V	± 20%				EX-1	FI	LFPV-(1,2)Apparent Fail.	A.R.				18,19,20	
TfL-5	1	0-700°R	± 5°R	20°R/sec	D	GH_2	T-2	FI	LH_2 Supply Failure	A.R.				18,19,20	
								R	Load & Purge	A.R.					
LOPV-1,2	2	O/C		0.5 sec	CE	GO_2	PN-2A	R	Load, Boost, Purge	A.R.				18,19,20	
LFPV-1,2	2	O/C		0.5 sec	CE	GH_2	PN-2A	R	Load, Boost, Purge	A.R.				18,19,20	
VOPV-1,2	2	0/28V	±20%				EX-1	FI	LOPV-1,2 No-Go	A.R.				18,19,20	

5

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 5.1 RCS Engine Subsystem

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PC-(5-13)	9	0-450 psia	± 2 psi	50000 psi/sec	D	Hot Gas	P-4	C	RCS Engine Start	A.R.				4,5,6	
								M	RCS Engine On	20/sec					
PC-(14-28)	15	0-450 psia	± 2 psi	50000 psi/sec	D	Hot Gas	P-4	C	RCS Engine Start	A.R.				1,2,3,	
								M	RCS Engine On	20/sec					
PC-(29-37)	9	0-450 psia	± 2 psi	50000 psi/sec	D	Hot Gas	P-4	C	RCS Engine Start	A.R.				4,5,6,	
								M	RCS Engine On	20/sec					
LBIV-(5-13)	9	0/C	-	0.5 sec	CE	-	PN-2A	R	Load & Purge	A.R.				4,5,6	
								R	Prior to RCS Start-up	E.O.					
LBIV-(14-28)	15	0/C	-	0.5 sec	CE	-	PN-2A	R	Load & Purge	A.R.				1,2,3,	
								R	Prior to RCS Start-up	E.O.					
LBIV-(29-37)	9	0/C	-	0.5 sec	CE	-	PN-2A	R	Load & Purge	A.R.				4,5,6	
								R	Prior to RCS Start-up	E.O					
LMBV-(5-13)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS Full Thrust	E.O.					
LBMV-(14-28)	15	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				1,2,3	
								R	RCS Full Thrust	E.O.					
LMBV-(29-37)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS Full Thrust	E.O.					
LIOV-(5-13)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS O_2 Ignition	E.O.					
LIOV-(14-28)	15	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				1,2,3	
								R	RCS O_2 Ignition	E.O.					
LIOV-(29-37)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS O_2 Ignition	E.O.					
LIFV-(5-13)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS H_2 Ignition	E.O.					
LIFV-(14-28)	15	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				1,2,3	
								R	RCS H_2 Ignition	E.O.					
LIFV-(29-37)	9	0/C	-	0.01 sec	CE	-	PN-6	R	Load & Purge	A.R.				4,5,6	
								R	RCS H_2 Ignition	E.O.					
VBIV-(5-37)	33	0/28 V	± 20%	-			EX-1	FI	LBIV Apparent Failure	A.R.					Diu Same as P.C.
VMBV-(5-37)	33	0/28 V	± 20%	-			EX-1	FI	LMBV Apparent Failure	A.R.					Diu Same as P.C.
VIOV-(5-37)	33	0/28 V	± 20%	-			EX-1	FI	LIOV Apparent Failure	A.R.					Diu Same as P.C.
VIFV-(5-37)	33	0/28 V	± 20%	-			EX-1	FI	LIFV Apparent Failure	A.R.					Diu Same as P.C.
VII-(5-37)	33	0/28 V	± 20%	-			VO-1	R	Load & Purge	A.R.					
								FI	Ignition Failure	A.R.					Diu Same as P.C.
IIE-(5-37)	33	Pulse		-			CU-1	FI	Ignition Failure	A.R.					Diu Same as P.C.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 5.2, Propellant Management

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PoT-4,5	2	0-50 psia	± 1.0psi	20 psi/sec	D	GO_2	P-1B	M	APU Blanket Pressure	1/sec				1,2,3,	For PoT-5
								R	Load & Purge	A.R.					
								FI	Low HE Pressure	A.R.				4,5,6	For PoT-4
PoT-6,7	2	0-2000 psia	±10 psi	1000 psi/sec	D	GO_2	P-7A	M,C	APU System Loaded	1/sec				1,2,3	For PoT-7
								R	Load & Purge	A.R.					
								FI	Low GO_2 Pressure	A.R.				4,5,6	For PoT-6
PfT-4,5	2	0-50 psia	±1.0 psi	20 psi/sec	D	GH_2	P-1B	M	APU Blanket Pressure	1/sec				1,2,3	For PfT-5
								R	Load & Purge	A.R.					
								FI	Low HE Pressure	A.R.				4,5,6	For PfT-4
PfT-6,7	2	0-2000 psia	±10 psi	1000 psi/sec	D	GH_2	P-7A	M	APU System Loaded	1/sec				1,2,3	For PfT-7
								R	Load & Purge	A.R.					
								FI	Low GH_2 Pressure	A.R.				4,5,6	For PfT-6
PoL-4,5	2	0-2000 psia	±10 psi	1000 psi/sec	D	GO_2	P-7A	FI	Low GO_2 Pressure	A.R.					Diu's as PoT-4,5
PfL-5,6	2	0-2000 psia	±10 psi	1000 psi/sec	D	GH_2	P-7A	FI	Low GH_2 Pressure	A.R.					Diu's as PfT-4,5
PoL-6,7	2	0-600 psia	± 4 psi	1000 psi/sec	D	GO_2	P-6	M	RCS or OMS Active	5/sec				1,2,3	For PoL-7
								R	Load & Purge	A.R.					
								FI	Thruster Supply Low	A.R.				4,5,6	For PoL-6
PfL-7,8	2	0-600 psia	± 4 psi	1000 psi/sec	D	GH_2	P-6	M	RCS or OMS Active	5/sec				1,2,3	For PfL-8
								R	Load & Purge	A.R.					
								FI	Thruster Supply Low	A.R.				4,5,6	For PfL-7
ToT-4,5	2	0-750°R	± 5°	200°/sec	D	GO_2	T-3	M	APU System Loaded	1/sec					Diu's as PoT-4,5
								R	Load & Purge	A.R.					
TfT-4,5	2	0-750°R	± 5°	200°/sec	D	GH_2	T-3	M	APU System Loaded	1/sed					Diu's as PfT-4,5
								R	Load & Purge	A.R.					
LOPV-(3-6)	4	O/C		0.5 sec	CE	GO_2	PN-2A	R	Prior to Thruster Firing	E.O.				1,2,3	For LOPV-(5-6)
								R	Load & Purge	A.R.					
								C	Regulator Failure	A.R.				4,5,6	For LOPV-(3,4)
LFPV-(3-6)	4	O/C		0.5 sec	CE	GH_2	PN-2A	R	Prior to Thruster Firing	E.O.				1,2,3	For LFPV-(5,6)
								R	Load & Purge	A.R.					
								C	Regulator Failure	A.R.				4,5,6	For LFPV-(3,4)
LOFV-2	1	O/C		0.5 sec	CE	GO_2	PN-2A	R	GO_2 Fill	A.R.				15,16,17	
LOFC-2	1	O/C		-	CE	GO_2	PN-3	R	GO_2 Fill	A.R.				15,16,17	
LFFV-2	1	O/C		0.5 sec	CE	GH_2	PN-2A	R	GH_2 Fill	A.R.				15,16,17	
LFFC-2	1	O/C		-	CE	GH_2	PN-3	R	GH_2 Fill	A.R.				15,16,17	
PoL-8,9	2	0-50 psia		20 psi/sec	D	GO_2	P-1A	M	APU Blanket Pressure	1/sec				1,2,3	For PoL-9
								R	Load & Purge	A.R.					
								FI	Low HE Pressure	A.R.				4,5,6	For PoL-8

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

(Continued)

SUBSYSTEM: 5.2, Propellant Management

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PfL-9,10	2	0-50 psia		20 psi/sec	D	GH_2	P-1A	M	APU Blanket Pressure	1/sec				1,2,3	For PfL-10
								R	Load & Purge	A.R.					
								FI	Low HE Pressure	A.R.				4,5,6	For PfL-9
VFPV-(3-6)	4	0/28 V	20%				EX-1	FI	Apparent Valve Failure	A.R.					See Valve For Diu
VOPV-(3-6)	4	0/28 V	20%				EX-1	FI	Apparent Valve Failure	A.R.					See Valve For Diu
VOFV-2	1	0/28 V	20%				EX-1	FI	Apparent Valve Failure	A.R.					See Valve For Diu
VFFV-2	1	0/28 V	20%				EX-1	FI	Apparent Valve Failure	A.R.					See Valve For Diu

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 5.3. ORB. A.P.S. Propel. Conditioning

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PC-(38-40)	3	0-1000 psia	±5 psi	50K psi/sec	D	Hot Gas	P-5	C	Subsystem Start & Shutdown	A.R.				9,10,11	Each to Separate Diu
								M	Shsystem Operation	1/sec					
PPTL-(1-3)	3	0-100 psig	± 1 psi	20 psi/sec	D	Oil	P-2A	M	Subsystem Operation	1/2 sec				9,10,11	Each to Separate Diu
								R	G.G. Startup	A.R.					
PPD-(1-3)	3	0-2000 psia	±10 psi	1500 psi/sec	D	LO_2	P-7	M	GO_2 Accum Resupply	2/sec				9,10,11	Each to Separate Diu
PPD-(4-6)	3	0-2000 psia	±10 psi	1500 psi/sec	D	LH_2	P-7	M	GH_2 Accum Resupply	2/sec				9,10,11	Each to Separate Diu
TC-(1-3)	3	0-2500°R	± 20°	200°/sec	D	Hot Gas	T-7	M	Subsystem Operation	1/sec				9,10,11	Each to Separate Diu
								R	G.G. Startup	A.R.					
TPTL-(1-3)	3	0-1300°R	± 10°	20 °/sec	D	Oil	T-5	M	Subsystem Operation	1/2 sec				9,10,11	Each to Separate Diu
								R	G.G. Startup	A.R.					
QPTL-(1-3)	3	0-6 inches	± .125"	12 in/sec	D	Oil	L-2	M	Subsystem Operation	1/2 sec				9,10,11	Each to Separate Diu
								R	G.G. Startup	A.R.					
NT-(1-3)	3	0-100K RPM	± 500	10K RPM/sec	D	-	SP-1	C	Subsystem Start-up	A.R.				9,10,11	Each to Separate Diu
								M	Subsystem Operation	2/sec					
LGOV-(1I-3I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsystem Readiness	E.O.				9,10,11	Each to Separate Diu
								R	Load & Purge	A.R.					
								FI	PC-(38-40) Out of Limit	A.R.					
LGFV-(1I-3I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Subsystem Readiness	E.O.				9,10,11	Each to Separate Diu
								R	Load & Purge	A.R.					
								FI	PC-(38-40) Out of Limit	A.R.					
LGOV-(1-3)	3	O/C	-	0.1 sec	CE	-	PN-6	C	Subsystem Start & Shutdown	E.O.				9,10,11	Each to Separate Diu
								R	Load & Purge	A.R.					
								FI	PC-(38-40) Out of Limit	A.R.					
LGFV-(1-3)	3	O/C	-	0.1 sec	CE	-	PN-6	C	Subsystem Start & Shutdown	E.O.				9,10,11	Each to Separate Diu
								R	Load & Purge	A.R.					
								FI	PC-(38-40) Out of Limit	A.R.					
LIOV-(38-40)	3	O/C	-	0.1 sec	CE	-	PN-6	C	Subsystem Start & Shutdown	E.O				9,10,11	Each to Separate Diu
								FI	PC-(38-40) Out of Limit	A.R.					
LIFV-(38-40)	3	O/C	-	0.1 sec	CE	-	PN-6	C	Subsystem Start & Shutdown	E.O.				9,10,11	Each to Separate Diu
								FI	PC-(38-40) Out of Limit	A.R.					
LLIV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Purge & GO_2 Resupply&Load	A.R.				9,10,11	Each to Separate Diu
								FI	PPD-(1-3) Out of limit	A.R.					
LFIV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Purge & GH_2 Resupply	A.R.				9,10,11	Each to Separate Diu
								FI	PPD-(4-6) Out of Limit	A.R.					
LPSV-(1-3)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	Purge & Resupply & Load	A.R.				9,10,11	Each to Separate Diu
								C	GO_2 Resupply	E.O.					
								FI	PPD-(1-3) Out of Limit	A.R.					

FOLDOUT FRAME 1

FOLDOUT FRAME 2

A-87 and A-88
(Continued)

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 5.3. ORB. A.P.S. Propel. Conditioning

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
LPSV-(4-6)	3	0/C	-	0.5 sec	CE	-	PN-2A	R	Purge & Load	A.R.				9,10,11	Each to Separate Diu
								C	GH_2 Resupply	E.O.					
								FI	PPD-(4-6) Out of Limit	A.R.					
VGOV-(11-31)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LGOV-(11-31) No-go	A.R.				9,10,11	Each to Separate Diu
VGFV-(11-31)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LGFV-(11-31) no-go	A.R.				9,10,11	Each to Separate Diu
VGOV-(1-3)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LGOV-(1-3) no-go	A.R.				9,10,11	Each to Separate Diu
VII-(38-40)	3	0/28 VDC	± 20%	-	-	-	EX-1	R	Load & Purge	A.R.				9,10,11	Each to Separate Diu
IIE-(38-40)	3	Pulse	-	-	-	-	CU-1	R	G.G. Start	A.R.				9,10,11	Each to Separate Diu
VIOV-(38-40)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LIOV-(38-40) no-go	A.R.				9,10,11	Each to Separate Diu
VIFV-(38-40)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LIFV-(38-40) no-go	A.R.				9,10,11	Each to Separate Diu
VLIV-(1-3)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LLIV-(1-3) no-go	A.R.				9,10,11	Each to Separate Diu
VFIV-(1-3)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LFIV-(1-3) no-go	A.R.				9,10,11	Each to Separate Diu
VPSV-(1-3)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LPSV-(1-3) no-go	A.R.				9,10,11	Each to Separate Diu
VPSV-(4-6)	3	0/28 VDC	± 20%	-	-	-	EX-1	FI	LPSV-(1-4) no-go	A.R.				9,10,11	Each to Separate Diu
NP-(1-3)	3	0-100K RPM	± 500	10K RPM/sec	D	-	SP-1A	FI	PPD-(1-3) Out of Limit	A.R.				9,10,11	Each to Separate Diu
AT-(1-3)	3	0-5g	± .05g	0-5000 Hz	CE	-	V-1	T	Subsystem Operation	TBD				9,10,11	
AP-(1-3)	3	0-5g	± .05g	0-5000 Hz	CE	-	V-1	T	GO_2 Resupply	TBD				9,10,11	
AP-(4-6)	3	0-5g	± .05g	0-5000 Hz	CE	-	V-1	T	GH_2 Resupply	TBD				9,10,11	
TPB-(1-3)	3	30-1000°R	± 10°	20 deg/sec	D	LO_2,GO_2	T-4	T	GO_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
TPB-(4-6)	3	30-1000°R	± 10°	20 deg/sec	D	LH_2,GH_2	T-4	T	GH_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
TPTB-(1-3)	3	400-1000°R	± 10°	20 deg/sec	D	Oil	T-5	T	Subsystem Operation	1/2 sec				9,10,11	Each to Separate Diu
NS-(1-3)	3	0-100K RPM	± 500	10K RPM/sec	CE	-	SP-1A	M	APU Operation	1/2 sec				9,10,11	Each to Separate Diu
AC-(1-3)	3	0-5g	± 0.5g	0-5000 Hz	CE	-	V-1	T	GO_2 Resupply	TBD				9,10,11	
AC-(4-6)	3	0-5g	± 0.5g	0-5000 Hz	CE	-	V-1	T	GH_2 Resupply	TBD				9,10,11	
AC-(7-9)	3	0-5g	± 0.5g	0-5000 Hz	CE	-	V-1	T	APU Operation	TBD				9,10,11	
THE-(1-3)	3	400-750°R	± 5°	200 Deg/sec	D	GO_2	T-3	M	GO_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
THE-(4-6)	3	400-750°R	± 5°	200 deg/sec	D	GH_2	T-3	M	GH_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
NP-(4-6)	3	0-100K RPM	± 500	10K RPM/sec	D	-	SP-1A	FI	PPD-(4-6) Out of Limit	A.R.				9,10,11	Each to Separate Diu
PHEO-(1-3)	3	0-1500 psia	±10 psi	1500 psi/sec	D	GO_2	P-7	M	GO_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
PHEO-(4-6)	3	0-1500 psia	±10 psi	1500 psi/sec	D	GH_2	P-7	M	GH_2 Resupply	1/2 sec				9,10,11	Each to Separate Diu
VGFV-(1-3)	3	0/28 VDC	±20%	-	-	-	EX-1	FI	LGFV-(1-3) No-Go	A.R.				9,10,11	Each to Separate Diu
VIEO-(1-3)	3	TBD	TBD	-	-	-	VO-2	FI	G.G. Ignition Failure	A.R.				9,10,11	Each to Separate Diu
PCV-(1-3)	3	0-1500	±10psia	1500 psi/sec	D	GO2	P-7	FI	PoT-7 Out-Of-Limit	A.R.				9,10,11	Each to Separate Diu
								FI	GO2 Resupply	A.R.					
PCV-(4-6)	3	0-1500 psia	±10 psia	1500 psi/sec	D	GH2	P-7	FI	PfT-7 Out-Of-Limit	A.R.				9,10,11	Each to Separate Diu
									GH2 Resupply	A.R.					

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 5.4, OMS Engine

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PC-(1-4)	4	0-450 psia	± 2 psi	50,000 psi/sec	D	Hot Gas	P-4	C	OMS Engine Start	A.R.				7, 8	
								M	OMS Engine On	20/sec					
LBIV-(1-4)	4	O/C	-	0.5 sec	CE	-	PN-2A	R	Load & Pruges, Prior to	A.R.				7, 8	
									RCS Start up						
LMBV-(1-4)	4	O/C	-	0.01 sec	CE	-	PN-6	R	OMS Full Thrust,Load&Purge	A.R.				7,8	
LIOV-(1-4)	4	O/C	-	0.01 sec	CE	-	PN-6	R	OMS Ignition, Load & Purge	A.R.				7, 8	
LIFV-(1-4)	4	O/C	-	0.01 sec	CE	-	PN-6	R	OMS Ignition, Load & Purge	A.R.				7, 8	
VBIV-(1-4)	4	0/28 V	20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				7, 8	
VMBV-(1-4)	4	0/28 V	20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				7, 8	
VIOV-(1-4)	4	0/28 V	20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				7, 8	
VIFV-(1-4)	4	0/28 V	20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				7, 8	
VII-(1-4)	4	0/28 V	20%	-	-	-	VO-1	FI	Ignition Failure	A.R.				7, 8	
								R	Load & Purge	A.R.					
IIE-(1-4)	4	Pulse		-	-	-	CU-1	FI	Ignition Failure	A.R.				7, 8	

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

SUBSYSTEM: 6.2, A/B Prop. Management

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
PPD-(7-9)	3	0-100 psia	± 2 psi	20 psi/sec	D	LH_2	P-2	M	A/B System Active	5/sec				12,13,14	
								R	Engine Start	A.R.					
								FI	Low LH_2 Supply Pres.	A.R.					
PC-(41-43)	3	0-1000 psia	± 5 psi	5000 psi/sec	D	Hot Gas	P-5	C	Gas Gen. Start-up	A.R.				12,13,14	
								M	A/B System Active	10/sec					
								FI	Low LH_2 Supply Pres.	A.R.					
PfL-(11-13)	3	0-60 psia	± 2 psi	20 psi/sec	D	LH_2	P-1	C	A/B Eng. Start OK	A.R.				12,13,14	
								R	Load & Purge	A.R.					
								M	A/B System Active	5/sec					Also Input to Eng. Controller
								FI	A/B Engine Failure	A.R.					
PTPL-(1-3)	3	0-100 psig	± 1 psi	20 psi/sec	D	Lube	P-2A	M	G.G. Running	1/2 sec				12,13,14	
								R	Engine Start	A.R.					
								FI	G.G. Failure	A.R.					
TC-(4-6)	3	0-2500°R	± 20°	200°/sec	D	Hot Gas	T-7	M	G.G. Running	1/sec				12,13,14	
								FI	G.G. Failure	A.R.					
TfL-(6-8)	3	0-100°R	± 5°	10°/sec	D	LH_2	T-1	C	A/B Eng. Start OK	A.R.				12,13,14	
								R	A/B Eng. Start	A.R.					Also Input to Eng. Controller
								M	A/B System Active	5/sec					
								FI	A/B Eng. Failure	A.R.					
TTPL-(1-3)	3	0-1300°R	± 10°	20°/sec	D	Lube	T-5	M	G.G. Running	1/2 sec				12,13,14	
								R	Engine Start	A.R.					
								FI	G.G. Failure						
QTPL-(1-3)	3	0-6 inches	± 1/8"	-	D	Lube	L-2	M	G.G. Running	1/2 sec				12,13,14	
								R	Engine Start	A.R.					
								FI	G.G. Failure	A.R.					
NT-(4-6)	3	0-100,000rpm	± 500	1000/sec	CE	-	SP-1	M	G.G. Running	5/sec				12,13,14	
								R	Engine Start	A.R.					
								FI	G.G. or Turbine Failure	A.R.					
LGFV-(4I-6I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	A/B System Start-up & Load	A.R.				12,13,14	
LGFV-(4-6)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	A/B System Start-up & Load	A.R.				12,13,14	
LGOV-(4I-6I)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	A/B System Start-up & Load	A.R.				12,13,14	
LGOV-(4-6)	3	O/C	-	0.5 sec	CE	-	PN-2A	R	A/B System Start-up & Load	A.R.				12,13,14	
LFIV-(4-6)	3	O/C	-	0.2 sec	CE	-	PN-4	R	A/B System Start-up & Load	A.R.				12,13,14	
LPSV-(7-9)	3	O/C	-	0.2 sec	CE	-	PN-4	R	A/B System Start-up & Load	A.R.				12,13,14	
LEFV-(1-12)	12	O/C	-	0.2 sec	CE	-	PN-4	R	A/B System Start-up & Load	A.R.				12,13,14	
VGFV-(4I-6I)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VGFV-(4-6)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	

TABLE A-1 (Cont.)

OCMS MEASUREMENT REQUIREMENTS

A-93 and A-94

(Continued)

SUBSYSTEM: 6.2, A/B Prop. Management

IDENTITY CODE	QTY.	RANGE & UNITS	ALLOW. ERROR	RESPONSE RATE	MTG.	FLUID MEDIA	MEAS. TYPE	DATA USE	TIME OF DATA ACTIVITY	SAMPLE RATE		DATA RATE		DIU NO.	REMARKS
VGOV-(4I-6I)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VGOV-(4-6)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VFIV-(4-6)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VPSV-(7-9)	3	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VEFV-(1-12)	12	0/28 V	± 20%	-	-	-	EX-1	FI	Apparent Valve Failure	A.R.				12,13,14	
VII-(41-43)	3	0/28 V	± 20%	-	-	-	VO-1	R	G.G. Start-up	E.O.				12,13,14	
VIEO-(4-6)	3	TBD		-	-	-	VO-2	FI	G.G. Start-up	A.R.				12,13,14	
IIE-(41-43)	3	TBD	-	-	-	-	CU-2	R	Engine Start.	A.R.				12,13,14	
								FI	Igniter Failure	A.R.					
AT-(4-6)	3	0.5 g	± 0.5 g	0-5000 HZ	CE	-	V-1	M	Turbine Running	TBD					
AP-(7-9)	3	0.5 g	± 0.5 g	0-5000 HZ	CE	-	V-1	M	Pump Running	TBD					

TABLE A-2

MEASUREMENT IDENTITY CODES

This table describes the measurement identity codes of Table A-1. The codes are listed by types in the following sections:

A. Main Engine
B. Airbreathing Engine
C. Orbiter (less engines)
D. Booster (less engines)

A. MAIN ENGINE

IDENTITY CODE	PARAMETER DESCRIPTION
$P_f LPTPA_s$	Pressure, Fuel; LPFTPA Suction
$P_f LPTPAT_i$	Pressure, Fuel; LPFTPA Turbine Inlet
$P_f LPTPA_d$	Pressure, Fuel; LPFTPA Discharge
$P_c FPB$	Chamber Pressure, FPB
$P_o LPTPA_s$	Pressure, Oxidizer; LPOTPA Suction
$P_o LPTPA_d$	Pressure, Oxidizer; LPOTPA Discharge
$P_c OPB$	Chamber Pressure, OPB
$P_{he} HPOTPA$	Pressure, Helium; HPOTPA Seal Cavity
$P_o HPTPATB$	Pressure, Oxidizer; HPOTPA Thrust Balancer
$P_c MCC$	Chamber Pressure; Main Combustion Chamber
P_{vac}-FL()	Vacuum Pressure, Fuel Line No. ( )
$P_o PBFM_o$	Pressure, Oxidizer; Preburners Flowmeter Outlet
$P_o MCCFM_o$	Pressure, Oxidizer, Main Combustion Chamber Flowmeter Outlet
$P_f FPB_i$	Pressure, Fuel; Fuel Preburner Inlet
$P_f OPB_i$	Pressure, Fuel; Oxidizer Preburner Inlet
$\Delta P_f FPBI/C$	Differential Pressure, Fuel; Fuel Preburner Inlet to Combustion Chamber
$\Delta P_f OPBI/C$	Differential Pressure, Fuel; Oxidizer Preburner Inlet to Combustion Chamber
$\Delta PCI/G$	Differential Pressure; Nozzle Coolant Inlet to Hot Gas Manifold

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

A. MAIN ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
P_oHEO	Pressure, Oxidizer; Heat Exchanger Outlet (Autogenous System)
P_fNCO	Pressure, Fuel; Nozzle Coolant Outlet (Autogenous System)
P_{he}FTPCV$_i$	Pressure, Helium; Main TCA Fuel Purge Check Valve Inlet
P_{he}OTPCV$_i$	Pressure, Helium; Main TCA Oxidizer Purge Check Valve Inlet
P_{he}PBSV$_o$	Pressure, Helium; Preburners Purge Solenoid Valve Outlet
PPS	Pressure, Purge System
P_hS	Pressure, Hydraulic System
P_hA	Pressure, Hydraulic Accumulator
ΔPGAP	Differential Pressure; Gimbal Actuator, Pitch
ΔPGAY	Differential Pressure; Gimbal Actuator, Yaw
ΔPHF	Differential Pressure; Hydraulic System Filter
P_oHPTPA(S2)$_d$	Pressure, Oxidizer; HPOTPA Stage 2 Discharge
P_oHPTPA(S1)$_d$	Pressure, Oxidizer; HPOTPA Stage 1 Discharge
T_cFPB	Temperature, Fuel Preburner Combustion Chamber
T_cOPB	Temperature, Oxidizer Preburner Combustion Chamber
T_oPBFM$_o$	Temperature, Oxidizer; Preburners Flowmeter Output
T_fLPTPA$_s$	Temperature, Fuel; LPFTPA Suction
T_fFRL	Temperature, Fuel Recirculation Line
T_oMCCFM$_o$	Temperature, Oxidizer; Main Combustion Chamber Flowmeter Outlet
T FPB	Temperature, Fuel; Fuel Preburner Inlet

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

A. MAIN ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
T_fOPB_i	Temperature, Fuel; Oxidizer Preburner Inlet
T_oLPTPA_s	Temperature, Oxidizer; LPOTPA Suction
LFMV	Position, Fuel Main Valve
LOMV	Position, Oxidizer Main Valve
LOPBFCV	Position, OPB Fuel Control Valve
LOPBOCV	Position, OPB Oxidizer Control Valve
LFPBOCV	Position, FPB Oxidizer Control Valve
LORSV	Position, Oxidizer Recirculation Select Valve
LFRSV	Position, Fuel Recirculation Select Valve
LFRCV	Position, Fuel Recirculation Control Valve
LGAP	Position, Gimbal Actuator, Pitch
LGAY	Position, Gimbal Actuator, Yaw
LEN	Position, Extendible Nozzle
LIOVOPB	Position, Igniter Oxidizer Valve, OPB
LIOVFPB	Position, Igniter Oxidizer Valve, FPB
LIOVMCC	Position, Igniter Oxidizer Valve, Main Combustion Chamber
LPOPSV	Position, Preburner Oxidizer Purge Solenoid Valve
LMOPSV	Position, Main TCA Oxidizer Purge Solenoid Valve
LMFPSV	Position, Main TCA Fuel Purge Solenoid Valve
LHSCPSV	Position, HPOTPA Seal Cavity Purge Solenoid Valve
LESPSV	Position, Engine System Purge Solenoid Valve
LPSV	Position, Purge Select Solenoid Valve (GN_2/GHe)
LENSV	Position, Extendible Nozzle Coolant Valve

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

A. MAIN ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
LEN_A	Position, Extendible Nozzle, Track A
LEN_B	Position, Extendible Nozzle, Track B
LEN_C	Position, Extendible Nozzle, Track C
$LENL_A$	Position, Extendible Nozzle Lock, Track A
$LENL_B$	Position, Extendible Nozzle Lock, Track B
$LENL_C$	Position, Extendible Nozzle Lock, Track C
LNLP	Position, Gimbal Actuator Null Lock, Pitch
LNLY	Position, Gimbal Actuator Null Lock, Yaw
IIMCC	Current, M.C.C. Igniter
IIOPB	Current, OPB Igniter
IIFPB	Current, FPB Igniter
NLPFTPA	RPM, LPFTPA
NHPFTPA	RPM, HPFTPA
NLPOTPA	RPM, LPOTPA
NHPOTPA	RPM, HPOTPA
ALPFTPA	Vibration (Acoustic Emission), LPFTPA
AHPFTPA	Vibration (Acoustic Emission), HPFTPA
ALPOTPA	Vibration (Acoustic Emission), LPOTPA
AHPOTPA	Vibration (Acoustic Emission), HPOTPA
FMOPB	Oxidizer Flowmeter, Preburners
FMOMCC	Oxidizer Flowmeter, Main Combustion Chamber
DIOPB	Ignition Detector, OPB
DIFPB	Ignition Detector, FPB
DIMCC	Ignition Detector, MCC
Q_hHSR	Level, Hydraulic Supply Reservoir

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

A. MAIN ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
FMFPBhe	Flow, Fuel Preburner Oxidizer Purge
FMOPBhe	Flow, Oxidizer Preburner Oxidizer Purge
$T_f FMV_o$	Temperature, Fuel Main Valve Outlet
$T_o OMV_o$	Temperature, Oxidizer Main Valve Outlet
TENCVd	Temperature, Nozzle Coolant Valve Discharge
tLIOVOPB	Time, Igniter Oxidizer Valve, Oxidizer Preburner
tLIOVFPB	Time, Igniter Oxidizer Valve, Fuel Preburner
tLIOVMCC	Time, Igniter Oxidizer Valve, Main Combustion Chamber
tLPOPSV	Time, Preburner Oxidizer Purge Solenoid Valve
tLMOPSV	Time, Main TCA Oxidizer Purge Solenoid Valve
tLMFPSV	Time, Main TCA Fuel Purge Solenoid Valve
tLENCV	Time, Extendible Nozzle Coolant Valve

B. AIRBREATHING ENGINE

PfCCI	Pressure, Fuel Combustion Chamber Inlet
PLPD	Pressure, Lube Pump Discharge
PSPD	Pressure, Scavenger Pump Discharge
PG	Pressure, Gearbox
PFI	Pressure, Fan Inlet Air
PHPT	Pressure, High Pressure Turbine
PED	Pressure, Exhaust Duct
PDVDVP	Pressure, Differential, Variable Displacement Vane Pump

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

B. AIRBREATHING ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
PZGL	Pressure, Zero-G Lube
TfCCI	Temperature, Fuel Combustion Chamber Inlet
TSPD	Temperature, Scavenger Pump Discharge
TIA	Temperature, Inlet Air
THPT	Temperature, High Pressure Turbine
TED	Temperature, Exhaust Duct
TLPTD	Temperature, Low Pressure Turbine Discharge
TCI	Temperature, Core Inlet
TTB	Temperature, Turbine Blade
TFH	Temperature, Fuel Heater
F_fF	Flow, Fuel
QLO	Quantity, Lube Oil
NHPT	RPM, High Pressure Turbine
NF	RPM, Fan
NVDVP	RPM, Variable Displacement Vane Pump
AFFB	Vibration, Front Fan Bearing
AFCB	Vibration, Front Core Bearing
ALPRB	Vibration, Low Pressure Rear Bearing
LCPRV	Position, Cooldown & Pressure Relief Valve
LFIVA/B	Position, Fuel Inlet Valve
LSDV	Position, Shutoff and Dump Valve

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

B. AIRBREATHING ENGINE (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
VFIVA/B	Excitation, Fuel Inlet Valve
VSDV	Excitation, Shutoff and Dump Valve
VC	Excitation, Cartridge (Solid Start)
VIIA/B	Voltage, Igniter Input
VIEO	Voltage, Igniter Exciter Output
VFH	Voltage, Fuel Heater
VCPRV	Excitation, Cooldown & Pressure Relief Valve
III	Current, Igniter Input
IFH	Current, Fuel Heater
FLB	Detector, Burner Flame
ACEC	Acoustic Monitor, Engine Compartment

C. ORBITER (less engines)

LOIV-1,2	Position, Oxidizer Isolation Valves; V-1,2
LOVV-(1-4)	Position, Oxidizer Vent Valves; V-(3-6)
LOFV-1	Position, Oxidizer Fill Valves; V-7
LFIV-1,2	Position, Fuel Isolation Valves; V-8,9
LFTVV-(1-4)	Position, Fuel Tank Vent Valves; V-(10-13)
LFFV-1	Position, Fuel Fill Valve; V-14
LOPCV-1,2	Position, Oxidizer Pressurization Control Valves; V-19,20.
LFPCV-1,2	Position, Fuel Pressurization Control Valves; V-21,22
LOIV-3	Position, Oxidizer Isolation Valve; V-23

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines)

IDENTITY CODE	PARAMETER DESCRIPTION
LOTVV-1,2	Position, Oxidizer Tank Vent Valves; V-24,25
LFIV-3,4	Position, Fuel Isolation Valves; V-26,27
LFTVV-(5-8)	Position, Fuel Tank Vent Valves; V-(28-31)
LOPV-1,2	Position, Oxidizer Pressurization Valves; V-32,33
LFPV-1,2	Position, Fuel Pressurization Valves; V-34,35
LOFC-1	Position, Oxidizer Fill Coupling; C-1
LHC-1,2	Position, Helium Coupling-Oxidizer; C-2
LFTVC-1	Position, Fuel Tank Vent Coupling; C-3
LHC-3,4	Position, Helium Coupling-Fuel; C-4
LFFC-1	Position, Fuel Fill Coupling; C-5
LHC-5,6	Position, Helium Coupling-Oxidizer; C-6
LHC-7,8	Position, Helium Coupling-Fuel; C-8
LFVC-1	Position, Fuel Vent Coupling; C-11
LBIV-(1-37)	Position, Bi-propellant Isolation Valve; Thrust Chamber-(1-37)
LMBV-(1-37)	Position, Main Bi-propellant Isolation Valve; Thrust Chamber-(1-37)
LIOV-(1-37)	Position, Igniter Oxidizer Valve; Thrust Chamber-(1-37)
LIFV-(1-37)	Position, Igniter Fuel Valve; Thrust Chamber (1-37)
LOPV-(3-6)	Position, Oxidizer Pressurization Valves; V-(36-39)
LFPV-(3-6)	Position, Fuel Pressurization Valves; V-(40-43)
LGOV-(1I-3I)	Position, GO2 Isolation Valves; GOV-(1-3)
LGFV-(1I-3I)	Position, GH2 Isolation Valves; GFV-(1-3)
LGOV-(1-3)	Position, GO2 Propellant Valves; GOV-(1-3)

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines)

IDENTITY CODE	PARAMETER DESCRIPTION
LGFV-(1-3)	Position, GH2 Propellant Valves; GFV-(1-3)
LIOV-38,39,40	Position, Igniter Oxidizer Valves; G-(1-3)
LIFV-38,39,40	Position, Igniter Fuel Valves; G-(1-3)
LLIV-1,2,3	Position, LO2 Isolation Valves; V-52,53,54
LPSV-1,2,3	Position, Pump Suction Valves; V-52,53,54
LFIV-1,2,3	Position, Fuel Isolation Valves; V-55,56,57
LPSV-4,5,6	Position, Pump Suction Valves; V-55, 56,57
LGOV-(4I-6I)	Position, GO2 Isolation Valves; GOV-(4-6)
LGFV-(4I-6I)	Position, GH2 Isolation Valves; GFV-(4-6)
LGOV-(4-6)	Position, GO2 Propellant Valves; GOV-(4-6)
LGFV-(4-6)	Position, Gh2 Propellant Valves; GFV-(4-6)
LFIV-4,5,6	Position, Fuel Isolation Valves; V-58,60,62
LPSV-7,8,9	Position, Pump Suction Valves; V-59,60,61
LEFV-(1-12)	Position, Engine Feed Valves; EFV-(1-12)
LOFV-2	Position, Oxidizer Fill Valve; V-44
LOFC-2	Position, Oxidizer Fill Coupling; C-9
LFFV-2	Position, Fuel Fill Valve; V-70
LFFC-2	Position, Fuel Fill Coupling; C-10
PfT-1	Pressure, Fuel tank; T-3 Ullage
PfT-2	Pressure, Fuel tank; T-5 Ullage
PfT-3	Pressure, Fuel Tank; T-6 Ullage
PoT-1	Pressure, Oxidizer Tank; T-1 Ullage
PoT-2	Pressure, Oxidizer Tank; T-2 Ullage
PoT-3	Pressure, Oxidizer Tank; T-4 Ullage

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
PoF-1	Pressure, Oxidizer Fill Line
PoS-1,2	Pressure, Oxidizer Suction Line, L-3,4
PoL-(1-3)	Pressure, Oxidizer Distribution Lines; L-17,18
PfS-1,2	Pressure, Fuel Suction Lines; L-8,9
PfF-1	Pressure, Fuel Fill Line
PfL-(1-4)	Pressure, Fuel Distribution Lines; L-20,21
PgF-1	Pressure, GH2 Autogenous Line; L-14
PgF-2	Pressure, GH2 Autogenous Line; Near V-21
PgF-3	Pressure, GH2 Autogenous Line; L-16
PgO-1	Pressure, Oxidizer Autogenous Line; L-13
PgO-2	Pressure, Oxidizer Autogenous Line; Near V-19
PgO-3	Pressure, Oxidizer Autogenous Line; Near O-3,4
PgRL-1	Pressure, Helium Recirculation-Oxidizer Line; L-7
PoT-4,5	Pressure, GO2 Accumulators; T-8,9 (Blanket)
PoT-6,7	Pressure, GO2 Accumulators; T-8,9
PfT-4,5	Pressure, GH2 Accumulators; T-10,11 (Blanket)
PfT-6,7	Pressure, GH2 Accumulators; T-10,11
PoL-4,5	Pressure, Regulator Inlet; F-6,7
PfL-5,6	Pressure, Regulator Inlet; F-8,9
PoL-6,7	Pressure, Oxidizer Feedline
PfL-7,8	Pressure, GH2 Feedline
PoL-8,9	Pressure, Oxidizer Feedline
PfL-9,10	Pressure, GH2 Feedline
PoL-10	Pressure, Regulator Inlet; F-4
PC-(5-37)	Pressure, Chamber; Thrust Chamber-(5-37)

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
PC-(1-4)	Pressure, Chamber; Thrust Chamber-(1-4)
PC-(38-40)	Pressure, Chamber; G-(1-3)
PPTL-(1-3)	Pressure, Power Train Lube; PT-(1-3)
PPD-(1-6)	Pressure, Pump Discharge; P-(1-6)
PHEO-(1-6)	Pressure, Heat Exchanger Output; H-(4-9)
PCV-(1-6)	Pressure, Check Valves; V-(46-51)
PfL-11	Pressure, Regulator Inlet; F-5
PPD-(7-9)	Pressure, Pump Discharge; P-(7-9)
PC-(41-43)	Pressure, Chamber; G-(4-6)
PfL-(11-13)	Pressure, Fuel Line; Fan Inlets
PTPL-(1-3)	Pressure, Turbopump Lube; P-(7-9)
TfT-1	Temperature, Fuel Tank; T-3 Ullage
TfT-2	Temperature, Fuel Tank; T-5 Ullage
TfT-3	Temperature, Fuel Tank; T-6 Ullage
ToT-1	Temperature, Oxidizer Tank; T-1 Ullage
ToT-2	Temperature, Oxidizer Tank; T-2 Ullage
ToT-3	Temperature, Oxidizer Tank; T-4 Ullage
ToS-1,2	Temperature, Oxidizer Suction Lines; L-3,4
TfS-1,2	Temperature, Fuel Suction Lines; L-8,9
TgF-1,2	Temperature, Fuel Autogenous Lines; L-14
TgO-1,2	Temperature, Oxidizer Autogenous Lines; L-13
TfL-(1-5)	Temperature, Fuel Distribution Lines; L-20,21
ToL-(1-4)	Temperature, Oxidizer Distribution Lines, L-17,18
ToT-4,5	Temperature, GO2 Accumulators; T-8,9

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
TfT-4,5	Temperature, GH2, Accumulator; T-10,11
TC-(1-3)	Temperature, Chamber; G-(1-3)
TPTL-(1-3)	Temperature, Power Train Lube; PT-(1-3)
THE-(1-6)	Temperature, Heat Exchanger; H-(4-9)
TPB-(1-6)	Temperature, Pump Bearings; P-(1-6)
TPTB-(1-3)	Temperature, Power Train Bearings; PT-(1-3)
TC-(4-6)	Temperature, Chamber; G-(4-6)
TfL-(6-8)	Temperature, Fuel Line; Fan Inlet
TTPL-(1-3)	Temperature, Turbopump Lube; U-(4-6), P-(7-9)
QfT-(1-3)	Quantity, Fuel Tank; T-3 (Bottom, Middle, Top)
QfT-(4-6)	Quantity, Fuel Tank; T-5 (Bottom, Middle Top)
QfT-(7-9)	Quantity, Fuel Tank; T-6 (Bottom, Middle, Top)
QoT-(1-3)	Quantity, Oxidizer Tank; T-1 (Bottom, Middle, Top)
QoT-(4-6)	Quantity, Oxidizer Tank; T-2 (Bottom, Middle, Top)
QoT-(7-9)	Quantity, Oxidizer Tank; T-4 (Bottom, Middle, Top)
QPTL-(1-3)	Quantity, Power Train Lube; PT-(1-3)
QTPL-(1-3)	Quantity, Turbopump Lube; P-(7-9)
NT-(1-3)	RPM, Turbines; U-(1-3)
NP-(1-6)	RPM, Pumps; P-(1-6)
NS-(1-3)	RPM, APU Shaft; PT-(1-3)
NT-(4-6)	RPM, Turbines; U-(4-6)

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
VOIV-1,2	Excitation, Oxidizer Isolation Valves; V-1,2
VOVV-(1-4)	Excitation, Oxidizer Vent Valves; V-(3-6)
VOFV-1	Excitation, Oxidizer Fill Valve; V-7
VFIV-1,2	Excitation, Fuel Isolation Valves; V-8,9
VFTVV-(1-4)	Excitation, Fuel Tank Vent Valves; V-(10-13)
VFFV-1	Excitation, Fuel Fill Valve; V-14
VOPCV-1,2	Excitation, Oxidizer Pressurization Control Valves; V-19,20
VFPCV-1,2	Excitation, Fuel Pressurization Control Valves; V-21,22
VOIV-3	Excitation, Oxidizer Isolation Valve; V-23
VOTVV-1,2	Excitation, Oxidizer Tank Vent Valves; V-24,25
VFIV-3,4	Excitation, Fuel Isolation Valves; V-26,27
VFTVV-(5-8)	Excitation, Fuel Tank Vent Valves; V-(28-31)
VOPV-1,2	Excitation, Oxidizer Pressurization Valves; V-32,33
VFPV-1,2	Excitation, Fuel Pressurization Valves; V-34,35
VBIV-(1-37)	Excitation, Bi-propellant Isolation Valves; Thrust Chamber-(1-37)
VMBV-(1-37)	Excitation, Main Bi-propellant Valve; Thrust Chamber-(1-37)
VIOV-(1-37)	Excitation, Igniter Oxidizer Valve; Thrust Chamber-(1-37)
VIFV-(1-37)	Excitation, Igniter Fuel Valve; Thrust Chamber-(1-37)
VOPV-(3-6)	Excitation, Oxidizer Pressurization Valves; V-(36-39)
VFPV-(3-6)	Excitation, Fuel Pressurization Valves; V-(40-43)

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
VGOV-(1I-3I)	Excitation, GO2 Isolation Valves; GOV-(1-3)
VGFV-(1I-3I)	Excitation, GH2 Isolation Valves; GFV-(1-3)
VGOV-(1-3)	Excitation, GO2 Propellant Valves; GOV-(1-3)
VGFV-(1-3)	Excitation, GH2 Propellant Valves; GFV-(1-3)
VIOV-38,39,40	Excitation, Igniter Oxidizer Valves; G-(1-3)
VIFV-38,39,40	Excitation, Igniter Fuel Valves; G-(1-3)
VLIV-1,2,3	Excitation, LO2 Isolation Valves; V-52, 53,54
VPSV-1,2,3	Excitation, Pump Suction Valves; V-52,53,54
VFIV-1,2,3	Excitation, Fuel Isolation Valves; V-55,56,57
VPSV-4,5,6	Excitation, Pump Suction Valves; V-55,56,57
VGOV-(4I-6I)	Excitation, GO2 Isolation Valves; GOV-4-6)
VGFV-(4I-6I)	Excitation GH2 Isolation Valves; GFV-(4-6)
VGOV-(4-6)	Excitation, GO2 Propellant Valves; GOV-(4-6)
VGFV-(4-6)	Excitation, GH2 Propellant Valves; GFV-(4-6)
VFIV-4,5,6	Excitation, Fuel Isolation Valves; V-58,60,62
VPSV-7,8,9	Excitation, Pump Suction Valves; V-59, 60,61
VEFV-(1-12)	Excitation, Engine Feed Valves; EFV-(1-12)
VOFV-2	Excitation, Oxidizer Fill Valve; V-44
VFFV-2	Excitation, Fuel Fill Valve; V-70
VII-(1-37)	Voltage, Igniter Input; Thrust Chamber-(1-37)
VII-(38-40)	Voltage, Igniter Input; G-(1-3)
VIEO-(1-3)	Voltage, Igniter Exciter Output; G-(1-3)
VII-(41-43)	Voltage, Igniter Input; G-(4-6)
VIEO-(4-6)	Voltage, Igniter Exciter Output; G-(4-6)

TABLE A-2 (cont)

MEASUREMENT IDENTITY CODES

C. ORBITER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
IIE-(1-37)	Current, Igniter Input; Thrust Chamber-(1-37)
IIE-(38-40)	Current, Igniter Input; G-(1-3)
IIE-(41-43)	Current, Igniter Input; G-(4-6)
AT-(1-3)	Vibration, Turbine; U-(1-3)
AP-(1-6)	Vibration, Pump; P-(1-6)
AC-(1-9)	Vibration, Clutch; PT-(1-3)
AT-(4-6)	Vibration, Turbine; T-(4-6)
AP-(7-9)	Vibration, Pump; P-(7-9)

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines)

IDENTITY CODE	PARAMETER DESCRIPTION
LOIV-1,2 A&B	Position, Oxidizer Isolation Valve; V-1,2 A&B
LOVV-(1-4) A&B	Position, Oxidizer Vent Valve; V-(3-6) A&B
LOFV-1 A&B	Position, Oxidizer Fill Valve: V-7 A&B
LFIV-(1-7) A&B	Position, Fuel Isolation Valve; V-(8-14) A&B
LFVV-(1-4) A&B	Position, Fuel Vent-Valve: V-(15-18) A&B
LFFV-1 A&B	Position, Fuel Fill Valve: V-19 A&B
LOPCV-1,2 A&B	Position, Oxidizer Pressure Control Valve; V-20,21 A&B
LFPCV-1,2 A&B	Position, Fuel Pressure Control Valve; V-22,23 A&B
LOP-(1-7) A&B	Position, Oxidizer Prevalve V-(77-83) A&B
LOFC-1 A&B	Position, L02 Fill Coupling; C-1 A&B
LHC-1,2 A&B	Position, L02 Helium Recir. Coupling; C-2 A&B
LFVC-1 A&B	Position, Fuel Vent Coupling; C-3 A&B
LHC-3,4 A&B	Position, Helium Coupling - Fuel; C-4 A&B
LFFC-1 A&B	Position, Fuel Fill Coupling; C-5 A&B
LHC-5,6 A&B	Position, Helium Coupling-Oxidizer; C-6 A&B
LBIV-(1-38)	Position, Bi-Propellant Isolation Valve; TR-(1-38)
LMBV-(1-38)	Position, Main Bi-Propellant Valve; TR-(1-38)
LIOV-(1-38)	Position, Igniter Oxidizer Valve; TR-(1-38)
LIFV-(1-38)	Position, Igniter Fuel Valve; TR-(1-38)
LOPV-(1-8)	Position, Oxidizer Pressurization Valve; V-(29-36)
LFPV-(1-8)	Position, Fuel Pressurization Valves; V-(37-44)
LRIV-(1-3)	Posision, Resupply Isolation Valve: V-46,48,50

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
LRPV-(1-3)	Position, Resupply Propellant Valve; V-45,47,49
LGOV-(1I-9I)	Position, GO2 Isolation Valve; GOV-(1-9)
LGOV-(1-9)	Position, GO2 Propellant Valve; GOV-(1-9)
LGFV-(1I-9I)	Position, GH2 Isolation Valve; GFV-(1-9)
LGFV-(1-9)	Position, GH2 Propellant Valve; GFV-(1-9)
LIOV-(39-47)	Position, Igniter Oxidizer Valve; G-(1-9)
LIFV-(39-47)	Position, Igniter Fuel Valve; G-(1-9)
LFIV-(8-10)	Position, Fuel Isolation Valve: V-90,92,94
LPSV-(1-3)	Position, Pump Suction Valve; V-91,93,63
LOIV-(3-5)	Position, Oxidizer Isolation Valve; V-57,59,61
LTSV-(1-3)	Position, Turbocompressor Suction Valve; V-58,60,62
LFFC-2	Position, Fuel Fill Coupling; C-9
LFFV-2	Position, Fuel Fill Valve; V-88
LOFC-2	Position, Oxidizer Fill Coupling; C-8
LOFV-2	Position, Oxidizer Fill Valve; V-89
LFDV-(1-4) A&B	Position, Feul Distribution Valve; V-98,99,100 A&B
LFPV-(9-10) A&B	Position, Fuel Pressurization Valve; V-75,76 A&B
LFVV-(5-8) A&B	Position, Fuel Vent Valve; V-(70-73) A&B
LFVC-2 A&B	Position, Fuel Vent Coupling; C-10 A&B
LFFV-3 A&B	Position, Fuel Fill Valve; V-74 A&B
LEFV-(1-28) A&B	Position, Engine Feed Valve; EFV-(1-28)
PoT-1 A&B	Pressure, Oxidizer Tank Ullage; T-1 A&B
PoL-1,2 A&B	Pressure, Oxidizer Distribution Line; L-8,9 A&B

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE		PARAMETER DESCRIPTION
PoS-(1-7)	A&B	Pressure, Oxidizer Suction Line; L-(1-7) A&B
PfT-1	A&B	Pressure, Fuel Tank Ullage; T-2 A&B
PfS-(1-7)	A&B	Pressure, Fuel Suction Line; L-(13-19) A&B
PoF-1	A&B	Pressure, Oxidizer Fill Line; L-11 A&B
PfF-1	A&B	Pressure, Fuel Fill Line; L-21 A&B
Pg0-8	A&B	Pressure, Oxidizer Autogenous Line; Upstream F-1 A&B
Pg0-9	A&B	Pressure, Oxidizer Autogenous Line; DN stream F-1 A&B
Pg0-10	A&B	Pressure, Oxidizer Autogenous Line; L-24 A&B
PgF-8	A&B	Pressure, Fuel Autogenous Line; upstream F-2 A&B
PgF-9	A&B	Pressure, Fuel Autogenous Line; DNstream F-2 A&B
PgF-10	A&B	Pressure, Fuel Autogenous Line; L-23 A&B
PgRL-1	A&B	Pressure, Helium Recirculation Line; L-12 A&B
Pc-(1-38)		Pressure, Chamber; Thruster-(1-38)
PoL- 3,4		Pressure, Oxidizer Feedline; Fwd. RCS/Separation, Boom A
PoL-5		Pressure, Regulator Inlet; F-6
PoL-6,7		Pressure, Oxidizer Feedline; Aft Separation, Boom A
PoL-8		Pressure, Regulator Inlet; F-7
PoL-9,10		Pressure, Oxidizer Feedline; Fwd RCS/Separation, Boom B
PoL-11		Pressure, Regulator Inlet; F-4
PoL-12,13		Pressure, Oxidizer Feedline; Aft Separation, Boom B
PoL-14		Pressure, Regulator Inlet; F-5

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
PfL-1,2	Pressure, Fuel Feedline; Fwd. RCS/Separation, Boom A
PfL-3	Pressure, Regulator Inlet; F-10
PfL-4,5	Pressure, Fuel Feedline; Aft Separation, Boom A
PfL-6	Pressure, Regulator Inlet; F-11
PfL-7,8	Pressure, Fuel Feedline; Fwd. RCS/Separation, Boom B
PfL-9	Pressure, Regulator Inlet; F-8
PfL-10,11	Pressure, Fuel Feedline; Aft Separation, Boom B
PfL-12	Pressure, Regulator Inlet; F-9
PoT-2,3	Pressure, GO2 Accomulator; T-4
PoT-4,5	Pressure, GO2 Accumulator; T-5
PoT-6,7	Pressure, GO2 Accululator; T-6
PoT-8,9	Pressure, GO2 Accumulator; T-7
PfT-2,3	Pressure, GH2 Accumulator; T-8
PfT-4,5	Pressure, GH2 Accumulator; T-9
PfT-6,7	Pressure, GH2 Accumulator; T-10
PfT-8,9	Pressure, GH2 Accumulator; T-11
PHEO-(1-3)	Pressure, Heat Exchanger Outlet; H-(1-3)
Pc-(39-47)	Pressure, Chamber; G-(1-9)
PPTL-(1-9)	Pressure, Power Train Lube; PT-(1-9)
PPD-(1-3)	Pressure, Pump Discharge; P-(1-3)
PTI-(1-3)	Pressure, Turbocompressor Inlet; CU-(1-3)
PTD-(1-3)	Pressure, Turbocompressor Discharge; CU-(1-3)
PPS-(1-3)	Pressure, Pump Suction; P-(1-3)
PfT-10 A&B	Pressure, LH2 Cruise Tank; T-12 A&B

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE		PARAMETER DESCRIPTION
PfL-(13-19)		Pressure, Fuel Feedline; Turbofan Inlets
PfL-20	A&B	Pressure, Regulator Inlet; F-12 A&B
PCV-(1-3)		Pressure, Check Valve; V-(51-53)
PCV-(4-6)		Pressure, Check Valve; V-(85-87)
ToT-1	A&B	Temperature, Oxidizer Tank; Ullage T-1 A&B
TfT-1	A&B	Temperature, Fuel Tank; Ullage T-2 A&B
ToL-1,2	A&B	Temperature, Oxidizer Distribution Line; L-8,9 A&B
TfF-1	A&B	Temperature, Fuel Fill Line; DNstream V-19 A&B
ToS-(1-7)	A&B	Temperature, Oxidizer Suction Line; L-(1-7) A&B
TfS-(1-7)	A&B	Temperature, Fuel Suction Line; L-(13-19) A&B
TgO-(1-7)	A&B	Temperature, Oxidizer Autogenous Line; Engine Interface
TgF-(1-7)	A&B	Temperature, Fuel Autogenous Line; Engine Interface
THE-(1-3)	A&B	Temperature, Heat Exchanger; H-(1-3)
TPB-(1-3)		Temperature, Pump Bearing; P-(1-3)
ToT-(2-5)		Temperature, GO2 Accumulator; T-(4-7)
TfT-(2-5)		Temperature, GH2 Accumulator; T-(8-11)
Tc-(1-9)		Temperature, Chamber; G-(1-9)
TPTL-(1-9)		Temperature, Power Train Lube; PT-(1-9)
TCB-(1-3)		Temperature, Turbocompressor Bearings; CU-(1-3)
TfL-(1-7)		Temperature, Fuel Feedline; Engine Inlet
TfT-6	A&B	Temperature, Fuel Tank; T-12 A&B

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
QoT-(1-3) A&B	Quantity, Oxidizer Tank; T-1 A&B
QfT-(1-3) A&B	Quantity, Fuel Tank; T-2 A&B
QPTL-(1-9)	Quantity, Power Train Lube; PT-(1-9)
QfT-(4-9) A&B	Quantity, Cruise Tank; T-12 A&B
NT-(1-9)	(RPM); Turbine; U-(1-6), X-(1-3)
NP-(1-3)	(RPM), Pump; P-(1-3)
NTC-(1-3)	(RPM), Turbocompressor; CU-(1-3)
NS-(1-3)	(RPM), Turbine Output Shaft; X-(1-3)
AT-(1-3)	Vibration, Turbine; U-(1-3)
AP-(1-3)	Vibration, Pump; P-(1-3)
ATC-(1-3)	Vibration, Turbocompressor; CU-(1-3)
AT-(4-6)	Vibration, Turbine; U-(4-6)
AT-(7-9)	Vibration, Turbine; X-(1-3)
VOIV-1,2 A&B	Excitation, Oxidizer Isolation Valve; V-1,2 A&B
VOVV-(1-4) A&B	Excitation, Oxidizer Vent Valve; V-(3-6) A&B
VOFV-1 A&B	Excitation, Oxidizer Fill Valve; V-7 A&B
VFIV-(1-7) A&B	Excitation, Fuel Isolation Valve; V-(8-14) A&B
VFVV-(1-4) A&B	Excitation, Fuel Vent Valve; V-(15-18) A&B
VFFV-1 A&B	Excitation, Fuel Fill Valve; V-19 A&B
VOPCV-1,2 A&B	Excitation, Oxidizer Pressure Control Valve; V-20,21 A&B
VFPCV-1,2 A&B	Excitation, Fuel Pressure Control Valve; V-22,23 A&B

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
VOP-(1-7) A&B	Excitation, Oxidizer Prevalve; V-(77-83) A&B
VBIV-(1-38)A&B	Excitation, Bi-Propellant Isolation Valve; TR-(1-38)
VMBV-(1-38)	Excitation, Main Bi-Propellant Valve; TR-(1-38)
VIOV-(1-38)	Excitation, Igniter Oxidizer Valve; TR-(1-38)
VIFV-(1-38)	Excitation, Igniter Fuel Valve; TR-(1-38)
VOPV-(1-8)	Excitation, Oxidizer Pressurization Valve; V-(29-36)
VFPV-(1-8)	Excitation, Fuel Pressurization Valves; V-(37-44)
VRIV-(1-3)	Excitation, Resupply Isolation Valve; V-46,48,50
VRPV-(1-3)	Excitation, Resupply Propellant Valve; V-45,47,49
VGOV-(1I-9I)	Excitation, G02 Isolation Valve; GOV-(1-9)
VGOV-(1-9)	Excitation, G02 Propellant Valve; GOV-(1-9)
VGFV-(1I-9I)	Excitation, GH2 Isolation Valve; GFV-(1-9)
VGFV-(1-9)	Excitation, GH2 Propellant Valve; GFV-(1-9)
VIOV-(39-47)	Excitation, Igniter Oxidizer Valve; G-(1-9)
VIFV-(39-47)	Excitation, Igniter Fuel Valve; G-(1-9)
VFIV-(8-10)	Excitation, Fuel Isolation Valve; V-90,92,94
VPSV-(1-3)	Excitation, Pump Suction Valve; V-91,93,63
VOIV-(3-5)	Excitation, Oxidizer Isolation Valve; V-57,59,61.
VTSV-(1-3)	Excitation, Turbocompressor Suction Valve; V-53,60,62.
VFFV-2	Excitation, Fuel Fill Valve; V-88
VOFV-2	Excitation, Oxidizer Fill Valve; V-89

TABLE A-2

MEASUREMENT IDENTITY CODES

D. BOOSTER (less engines) (cont)

IDENTITY CODE	PARAMETER DESCRIPTION
VFDV-(1-4) A&B	Excitation, Fuel Distribution Valve; V-98,99,100, 84 A&B
VFPV-(9-10) A&B	Excitation, Fuel Pressurization Valve; V-75,76 A&B
VFVV-(5-8) A&B	Excitation, Fuel Vent Valve; V-(70-73) A&B
VFFV-3 A&B	Excitation, Fuel Fill Valve; V-74 A&B
VEFV-(1-28)	Excitation, Engine Feed Valve; EFV-(1-28)
VII-(1-38)	Voltage, Igniter Input; TR-(1-38)
VII-(39,47)	Voltage, Igniter Input; G-(1-9)
VIEO-(1-9)	Voltage, Igniter Exciter Output; G-(1-9)
IIE-(1-38)	Current, Igniter Input; TR-(1-38)
IIE-(39-47)	Current, Igniter Input; G-(1-9)

TABLE A-3

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-1-ME

RANGE(S): 0 - 50 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LH_2; GHE; GN_2

COMPENSATED OPERATING RANGE: $-420^{o}F$ to $-120^{o}F$

ERROR BAND OVER COMPENSATED RANGE: $\pm$ 0.5%, 3σ

OPERATING TEMPERATURE RANGE: $-420^{o}F$ to $+ 165^{o}F$

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V.D.C. Nominal

INPUT/OUTPUT RESISTANCE: Estimate: 1 K to 2 K ohms

ELECTRICAL CALIBRATION CHECK: Single internal shunt, by external contact closure.

SENSITIVITY: 3 MV/V. nominal

FLAT FREQUENCY RESPONSE: 20 Hz. (possible POGO application)

VIBRATION: Nominal 54 G. RMS, random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 54 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: Not Available

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-2-ME

RANGE(S): 0 - 3000 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LH_2; GHE; GN_2

COMPENSATED OPERATING RANGE: -420°F to -120°F

ERROR BAND OVER COMPENSATED RANGE: ± 1.0%, 3σ

OPERATING TEMPERATURE RANGE: -420°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V.D.C. nominal

INPUT/OUTPUT RESISTANCE: Estimate: 1 K to 2 K ohms.

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV./V nominal

FLAT FREQUENCY RESPONSE: 10 Hz

VIBRATION: Nominal 54 G. RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: Approximately 3600 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: Not Available

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time

CONNECTOR: (Not available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-3-ME

RANGE(S): 0 - 100 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LH_2; GHE; GN_2

COMPENSATED OPERATING RANGE: -420°F to -120°F

ERROR BAND OVER COMPENSATED RANGE: ± 1.0%, 3σ

OPERATING TEMPERATURE RANGE: -420°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V.D.C. nominal

INPUT/OUTPUT RESISTANCE: 1K to 2K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/Volt nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.2

PROOF PRESSURE: 150 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-4-ME

RANGE(S): 0 - 6000 psia, 0 - 3500 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: Hot Gas, H_2-Rich; GHE; GN_2

COMPENSATED OPERATING RANGE: 0 to +300°F

ERROR BAND OVER COMPENSATED RANGE: $\pm$ 0.5%, 3σ

OPERATING TEMPERATURE RANGE: -65 to +300°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V. D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 20 Hz (min)

VIBRATION: Nominal 45 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 7200 psia; 4000 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-5-ME

RANGE(S): 0 - 300 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LOX; GN_2

COMPENSATED OPERATING RANGE: -300°F to 0°F

ERROR BAND OVER COMPENSATED RANGE: $\pm$ 0.5%, 3σ

OPERATING TEMPERATURE RANGE: -300°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/Volt nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 360 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-6-ME

RANGE(S): 0 - 750 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LOX; GN_2

COMPENSATED OPERATING RANGE: -300°F to 0°F

ERROR BAND OVER COMPENSATED RANGE: $\pm$ 1%, 3σ

OPERATING TEMPERATURE RANGE: -300°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (Estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 840 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-7-ME

RANGE(S): 0 - 50 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: GHE, GOX, GH_2

COMPENSATED OPERATING RANGE: -100°F to +200°F

ERROR BAND OVER COMPENSATED RANGE: ± 1.5%, 3σ

OPERATING TEMPERATURE RANGE: -100°F to +200°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: $<$ 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 60 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-8-ME

RANGE(S): 0 - 8000 psia, 0 - 5000 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LOX; GN_2

COMPENSATED OPERATING RANGE: -300°F to 0°F

ERROR BAND OVER COMPENSATED RANGE: ± 1.5%, 3σ and ± 0.5%, 3σ

OPERATING TEMPERATURE RANGE: -300°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 100 Hz (estimate)

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 9,000 psia, 6,000 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability of untested units: 12 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-9-ME

RANGE(S): 0 - 100 microns

FLUID(S) IN CONTACT WITH DIAPHRAGM: Air, GH_2

COMPENSATED OPERATING RANGE: Ambient

ERROR BAND OVER COMPENSATED RANGE: ±20%

OPERATING TEMPERATURE RANGE: -65 to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Thermocouple

EXCITATION: Not Applicable

INPUT/OUTPUT RESISTANCE: Not Applicable

ELECTRICAL CALIBRATION CHECK: If sensor opens, zero output should result.

SENSITIVITY: Not Available - estimate one micron

FLAT FREQUENCY RESPONSE: 1 sec, zero to atm.

VIBRATION: Nominal 54G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE:

PROOF PRESSURE: 54 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: No estimate of availability, similar units supplied in past for missiles, but no direct applicability.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure Measurement Type: P-10-ME

RANGE(S): 0 - 7000 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: LH_2; GN_2

COMPENSATED OPERATING RANGE: -300°F to 0°F

ERROR BAND OVER COMPENSATED RANGE: ± 0.5%, 3σ

OPERATING TEMPERATURE RANGE: -300°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V. D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: 8400 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not available)

SHELF LIFE: 10 years

SPECIAL NOTES: 12 weeks, etc. etc.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure; 0-1500 psid Measurement Type: P-11-ME

RANGE(S): 0 - 1000 psid

FLUID(S) IN CONTACT WITH DIAPHRAGM: LH_2/GH_2: Hot Gas; GHE; GN_2

COMPENSATED OPERATING RANGE: -200 to +100°F

ERROR BAND OVER COMPENSATED RANGE: ± 0.75%, 3σ

OPERATING TEMPERATURE RANGE: -200°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: (Not Available)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE, NO CHANGE IN PERFORMANCE:

COLD SIDE: 6800 maximum working pressure

HOT SIDE: 6000 maximum working pressure

PROOF PRESSURE: 8160 psia

MOUNTING: (Not Available)

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: This item would require extensive development. At least 15 months for a prototype is required.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-12-ME

RANGE(S): 0 - 200 psid

FLUID(S) IN CONTACT WITH DIAPHRAGM: Cold GH_2; GHE; GN_2

COMPENSATED OPERATING RANGE: -300 to +0°F.

ERROR BAND OVER COMPENSATED RANGE: ± 2%, 3 σ

OPERATING TEMPERATURE RANGE: -300°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: (Not Available) estimate 350 to 2000 ohms.

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE, NO CHANGE IN PERFORMANCE:

HIGH SIDE: 7000 psia

LOW SIDE: 3800 psia

PROOF: 8400 psia

MOUNTING: (Not Available)

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Availability of untested units estimated 12 - 15 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-13-ME

RANGE(S): 0 - 1500 psia; 0 - 2000 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: GO_2; GH_2;GHE

COMPENSATED OPERATING RANGE: 0 - 300°F

ERROR BAND OVER COMPENSATED RANGE: ± 0.5%, 3

OPERATING TEMPERATURE RANGE: -65 to +300°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: 1 K to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: (Zero to full scale in 2 seconds)

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 4.0

PROOF PRESSURE: 8400 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Availability, untested units; 12 - 18 weeks, A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-14-ME

RANGE(S): 0 - 1500 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: GHE; GN_2

COMPENSATED OPERATING RANGE: -65° to +165°F

ERROR BAND OVER COMPENSATED RANGE: ± 1.5%, 3σ

OPERATING TEMPERATURE RANGE: -65°F to +165°F

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 10 V D.C. nominal

INPUT/OUTPUT RESISTANCE: .35 to 2 K ohms (estimated)

ELECTRICAL CALIBRATION CHECK: Single internal shunt by external contact closure.

SENSITIVITY: 3 MV/V nominal

FLAT FREQUENCY RESPONSE: Estimate 20 Hz

VIBRATION: Nominal 54 G's RMS random

OVER PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.2

PROOF PRESSURE: 2250 psia

MOUNTING: Direct, Flange

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

CONNECTOR: (Not Available)

SHELF LIFE: 10 years

SPECIAL NOTES: Estimated availability: 12 weeks A.R.O., untested.

TABLE A-3 (Cont.)

SENSOR CRITERIA

<u>HYDRAULIC SYSTEM MEASUREMENTS</u>: Measurement Type: P-15-ME

The system is undefined at this time.

As a minimum, system pressure, accumulator pressure, gimbal actuator ΔP's, filter ΔP, and reservoir level are required.

The flat response of the ΔP's should be 10 Hz (gimbal frequency).

Design limit pressure should be the basis for over-pressure capability, which must take into account the surge peaks. Also, proof should be 1.2 x design limit, and burst should be 1.5 x design limit.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Temperature   Measurement Type: T-16-ME

RANGE: $460^{o}R$ to $2200^{o}R$

PRECISION: $\pm 3^{o}R$

SENSING ELEMENT: Platinum

FLUID(S) IN CONTACT WITH PROBE: Hydrogen - rich combustion gas; GHE; GN_2

EXCITATION: Constant current

ELECTRICAL CALIBRATION CHECK: None in probe. Suggest four wire system, with calibration check circuitry in series with probe.

PRESSURE RATINGS:

MAX. WKG: 6000 psia

PROOF: 7200 psia

MOUNTING: Direct, Flange

TIME CONSTANT: $<$ 0.5 sec. in gas stream.

SELF HEATING ERROR: (Not Available)

STEM CONDUCTION ERROR: (Not Available)

INTERCHANGEABILITY: (Not Available)

VIBRATION: Nominal 54 G's RMS, random

OPERATING TEMPERATURE RANGE: $400^{o}R$ to $2200^{o}R$

CONNECTOR: (Not Available)

WEIGHT/VOLUME: (Not Available)

SHELF LIFE: 10 years

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

SPECIAL NOTES: Estimated availability of untested units, 12 - 18 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Temperature   Measurement Type: T-17-ME

RANGE: $30^{o}R$ to $300^{o}R$

PRECISION: $\pm 0.3^{o}R$; $\pm 0.6^{o}R$

SENSING ELEMENT: Platinum

FLUID(S) IN CONTACT WITH PROBE: LOX; LH_2; GN_2; GHE.

EXCITATION: Constant current

ELECTRICAL CALIBRATION CHECK: None in probe. Suggest four wire system with calibration check circuitry in series with probe.

PRESSURE RATINGS:

MAX. WKG: 7500 psia

PROOF: 9000 psia

MOUNTING: Direct, Flange

TIME CONSTANT: < 0.5 sec. in flowing liquid

SELF HEATING ERROR: (Not Available)

STEM CONDUCTION ERROR: (Not Available)

INTERCHANGEABILITY: (Not Available)

VIBRATION: Nominal 54 G's RMS, random

OPERATING TEMPERATURE RANGE: $30^{o}R$ to $565^{o}R$

CONNECTOR: (Not Available)

WEIGHT/VOLUME: (Not Available)

SHELF LIFE: 10 years

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

SPECIAL NOTES: Estimated availability of untested units: 12 - 18 weeks A.R.O.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Position, Analog, linear travel. Measurement Type: PN-18-ME

STROKE: 0.5"; 1"

LINEARITY: 0.5% nominal

RESOLUTION: infinite

RESISTANCE: 10,000 ohms nominal

EXCITATION: 10 V. D.C.

OPERATING TEMPERATURE RANGE: -200°F to +165°F

OPERATING PRESSURE RANGE: Ambient sea level to space vacuum.

VIBRATION: nominal 54 G's RMS, random

MINIMUM OPERATING CYCLE RATING: 5×10^6

INTERCHANGEABILITY: (Not Available)

MOUNTING: On components, external. (Details not available).

CONNECTOR: (Not Available)

WEIGHT/VOLUME: (Not Available)

ELECTRICAL CALIBRATION CHECK: Set end point mechanical travel to give a 5 or 10% voltage output residual, - if sensor opens, output voltage jumps to a forbidden level (requires stored logic).

AVAILABILITY: 12 - 18 weeks, depending upon configuration requirements.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Position, Discrete   Measurement Type: PN-19-ME

LOGIC: Two-level voltage output; $V_1 \cong$ 1 V D.C.; $V_2 \cong$ 28 V D.C.

OPERATING TEMPERATURE RANGE: -300°F to 165°F

HYSTERESIS: 0.001" to 0.005" (estimate)

APPLICATION: Direct-acting solenoid valves; extendible nozzle mechanisms; gimbal actuator null lock;

OPERATIONAL CHECK: Simulation of position change by external contact closure.

OPERATING PRESSURE RANGE: Sea level ambient to space vacuum.

MOUNTING: Component, external; (Details not available).

SPECIAL NOTES: In many cases, these sensors will be on solenoid valves with 0.030" to 0.050" travel. Redundant sensors in both open and closed positions may be required. The sensor should be integrated with the valve. Considerable development is anticipated.

CONNECTOR: (Not Available)

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Vibration   Measurement Type: V-20-ME

TEMPERATURE RANGE: -400°F to +165°F

DESCRIPTION: This sensor is intended to serve as a bearing/turbine/pump condition monitoring device. The principle impetus is the avoidance of a total bearing failure in a LOX pump. A secondary objective is to prevent a similar occurrence in an LH_2 pump.

The intended method for avoiding failure is to monitor acoustic emission during engine operation, recording data, and analyzing the data for trends and absolute limits.

The device is intended to be used as a flight safety monitor, to initiate an emergency shutdown in the event of detection of a level in excess of allowable.

The device must contain a self-check feature to be assured that (1) the transducer is functional, and, (2) the input/level discrimination circuits are functional.

SPECIAL NOTE: No device is known which is readily available. As a baseline, the technique described in the following paper is suggested: (1) "Incipient Failure Detection in Bearings," Harvey L. Balderston; (Boeing Company, Seattle Washington). American Society for Non-Destructive Testing, National Conference, 28th. Detroit, Michigan, October 14 - 17, 1968 Paper 17p.

OPERATING LIFE: 10 hours, engine operating; 3200 hours ground time.

VIBRATION: 54G's RMS random, to 2000 Hz.

SHELF LIFE: 10 years

CONNECTOR: (Not available)

INTERCHANGEABILITY: Replacement of the sensor must not require adjustment of electronics at a remote point. Software adjustment in the engine controller is permissible.

60

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Displacement Measurement Type: X-21-ME

TEMPERATURE RANGE: -420°F to +165°F

DESCRIPTION: This sensor is intended to serve as a bearing/turbine/pump condition monitoring device. The principle impetus is the avoidance of a total bearing failure in a LOX pump. A secondary objective is to prevent a similar occurrence in an LH_2 pump.

The intended method for avoiding failure is the detection of turbopump shaft displacement during engine operation, recording data, and analyzing for trends and absolute limits.

Based on wear patterns, a resolution of the order of 0.0001" to 0.0005", in a full scale range of perhaps 0.005" or 0.010" is required. Stability and calibration criteria must be determined on these values.

It is also intended that the sensor system be used as a flight safety monitor to initiate engine shutdown should deflection exceed predetermined levels.

The device must contain a self-check feature to assure that sensor and its associated electronics are functioning.

SPECIAL NOTE: No proven device is known to exist. The closest approach is a system built by Kaman Nuclear Company, Colorado Springs, Colorado. It is in use at Aerojet Liquid Rocket Company, in conjunction with the NERVA bearing test program. Resolutions to 0.0001" have been demonstrated.

OPERATING LIFE: 10 hours, engine operating; 3200 hours ground time.

VIBRATION: 54 G's RMS random, to 2000 Hz

SHELF LIFE: 10 years

CONNECTOR: (Not Available)

INTERCHANGEABILITY: Replacement of the sensor must not require adjustment of electronics at a remote point. Software adjustment within the engine controller is permissible.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Ignition   Measurement Type: D-22-ME

APPLICATION: Preburner and main combustion chambers.

RESPONSE TIME: 5 milliseconds

PRESSURE RATING:

MAX. WKG: 6000 psia
PROOF: 7200 psia

MIXTURE RATIO AT IGNITION: 2:1 (Approximately)

PROPELLANTS: Oxygen; hydrogen

IGNITION SOURCE: Spark

INTENDED USE: As a start sequence safety monitor, to initiate sequence termination if ignition is not sensed in (Not Available) seconds. The choice of response time is estimated based on desire to detect the successful ignition as rapidly as possible in relation to valve opening times and total engine start time. The actual ignition event may not occur until 0.1 to 0.5 seconds after initiation of the start signal.

INTERCHANGEABILITY: Replacement of a sensor shall not require adjustment to electronics in the engine controller. Software changes are permissible.

SELF CHECK: Sensor system shall contain a self-check feature which assures the sensor is functioning. The signal must be capable of interpretation by the engine controller

OPERATING LIFE: 10 hours accumulated mission time. Actual sensing time $\cong$ 150 seconds. 3200 hours ground operating time.

SHELF LIFE: 10 years

OUTPUT VOLTAGE: (Not Available) As high as possible up to 28 V.

AVAILABILITY: No device is known to exist. Infra-red sensing via a sapphire or quartz window is possible, but sealing effectiveness must be demonstrated.

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Flow Measurement Type: F-23-ME

RANGE: To 0.1 pounds/second

FLUID(S): GHE, GOX

OPERATING TEMPERATURE RANGE: -200°F to 165°F

PRESSURE:

WKG: 1500 psia
PROOF: 9000 psia

OUTPUT SIGNAL: May be analog or discrete. Discrete will be set for flow.

ALLOWABLE PRESSURE DROP: (Not Available) Must be minimized for maximum purge flow capability.

VIBRATION: Nominal 54 G's RMS random, to 2000 Hz

MOUNTING: In-line, Flange.

SELF-CHECK: Must contain electrical function check, stimulated by external contact closure, or other similar approach. Loss of continuity must be readily identifiable.

WEIGHT/VOLUME: (Not Available)

OPERATIONAL LIFE: 10 hours, engine operating; 3200 hours ground time.

SHELF LIFE: 10 years

CONNECTOR: (Not Available)

RESPONSE: 50 milliseconds, one time const.

REPEATABILITY: $\pm$ 5%, 3σ (set point or analog output)

SPECIAL NOTES: Estimated availability, 12 - 18 weeks A.R.O., untested units.

TABLE A-3 (Cont.)

SENSOR CRITERIA

This sheet is intended only to identify the need for RPM, flow, current, and liquid level sensors. Final system designs will dictate the requirements.

The RPM sensors are required for pumps. Operating temperature range is -420°F to +165°F.

The turbine flowmeters are in the engine baseline, but may be removed. The general requirement is for LOX flow to about 900 pounds/second, and fuel (LH_2) flow to about 150 pounds/second.

The liquid level system is reqired for the yet-to-be-defined hydraulic system.

Significant points to include:

a. Pressures

b. Vibration

c. Checkout

d. Precision

e. Response

f. Interchangeability

g. Operating Life

Measurement Type: CU-24-ME
SP-24-ME
F-24-ME
Q-24-ME

TABLE A-3 (Cont.)

SENSOR CRITERIA

PARAMETER: Pressure   Measurement Type: P-25-ME

RANGE(S): 0 - 500 psia

FLUID(S) IN CONTACT WITH DIAPHRAGM: GH_2; GOX; GHE, GN_2, 0^oF to $+250^oF$.

COMPENSATED OPERATING RANGE: 0 to $+250^oF$

OPERATING RANGE: -65^oF to $+ 250^oF$.

MAXIMUM EXPOSURE TEMPERATURE RANGE: (Not Available)

TYPE OF SENSING ELEMENT: Full Bridge

EXCITATION: 28 V. D.C.

INPUT/OUTPUT RESISTANCE: (Not Available)

OUTPUT SIGNAL: Digital

INTERNAL SAMPLING RATE: 100 to 1000 samples per second (value will be fixed, but is not chosen).

ERROR BAND OVER COMPENSATED RANGE: $\pm$ 2%, 3σ.

ELECTRICAL CALIBRATION CHECK: Internal shunt by external command.

FLAT FREQUENCY RESPONSE: Approximately 100 Hz.

VIBRATION: (Not Available)

MOUNTING: Direct, Flange.

OVER-PRESSURE FACTOR, NO CHANGE IN PERFORMANCE: 1.0

PROOF PRESSURE: (Not Available)

OPERATIONAL LIFE: (Not Available)

SHELF LIFE: 10 years

CONNECTOR: (Not Available)

AVAILABILITY: 12 - 18 weeks ARO untested units.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

TABLE A-4
SENSOR REQUIREMENTS
SUBSYSTEM: ALL (less main engines)

MEAS. TYPE NO.	PARAMETER DESCRIPTION	IDENTICAL MEAS. QUAN.		RANGE AND UNITS	MEAS. TOL.	RESPONSE TIME	ENVIRONMENT	RQMTS. SOURCE REF.			
								C/M ANAL.		FMEA	
		BOOS.	ORB.					BOOS.	ORB.	BOOS.	ORB.
P-1	PRESSURE	13	12	0-60 PSIA	± 2 PSI	20 PSI/SEC	LO_2, LH_2; GH_2, 700°R, FLUSH MNT	1.2 3.2	4.2 4.4 6.2	1.2 3.2	4.2 4.4
P-1A	PRESSURE	8	4	0-50 PSIA	± 1 PSI	20 PSI/SEC	GO_2, GH_2, He, 750°R, FLUSH MNT, OVER PRES. 800 PSIA	2.2	5.2	2.2	5.2
P-1B	PRESSURE	8	4	0-50 PSIA	± 1 PSI	20 PSI/SEC	GO_2, GH_2, He, 750°R, FLUSH MNT, OVER PRES. 2000 PSIA	2.2	5.2	2.2	5.2
P-2	PRESSURE	12	11	0-100 PSIA	± 1 PSI	50 PSI/SEC	LO_2, GO_2, LH_2, He, 700°R, FLUSH MNT	1.1 1.2	4.1 6.2	1.2 2.3	4.2 6.2
P-2A	PRESSURE	9	6	0-100 PSIG	± 1 PSI	20 PSI/SEC	LUBE OIL, 700°R, FLUSH MNT	2.4 2.3 2.4 2.6	4.2 5.3 6.2	2.4 2.3 2.4 2.6	5.3
P-3	PRESSURE	32	3	0-200 PSIA	± 2 PSI	20 PSI/SEC	LO_2, 700°R, FLUSH MNT	1.1 1.2	4.1 4.2	1.2	4.2
P-4	PRESSURE	38	37	0-750 PSIA	± 2 PSI	50,000 PSI/SEC	GO_2, GH_2, COMBUST., 5000°R. FLUSH MNT	2.1	5.1	2.1	5.1
P-5	PRESSURE	9	6	0-1000 PSIA	± 5 PSI	50,000 PSI/SEC	GO_2, GH_2, COMBUST., 1800°R, FLUSH MNT	2.5 2.3 2.4 2.6	5.4 5.3 6.2	2.5 2.3 2.4 2.6	5.4 5.3 6.2
P-6	PRESSURE	8	4	0-800 PSIA	± 4 PSI	1,000 PSI/SEC	GO_2, GH_2, He, 750°R, FLUSH MNT	2.2	5.2	2.2	5.2
P-6A	PRESSURE	12	6	0-1200 PSIA	± 10 PSI	500 PSI/SEC	GO_2, GH_2, He, 900°R, FLUSH MNT	1.3	4.3	1.3	4.5
P-7	PRESSURE	15	18	0-2000 PSIA	± 10 PSI	1,500 PSI/SEC	GO_2, LH_2, 530°R, FLUSH MNT	2.3 2.4	5.3	2.3 2.4 2.6	5.3
P-7A	PRESSURE	16	8	0-2000 PSIA	± 10 PSI	1,000 PSI/SEC	GO_2, GH_2, He, 750°R, FLUSH MNT	2.2	5.2	2.2	5.2
P-7B	PRESSURE	2	2	0-2000 PSIA	± 10 PSI	500 PSI/SEC	GO_2, GH_2, 750°R, FLUSH MNT	3.3	4.5	3.3	4.5
P-1-TF	PRESSURE	7	3	0-60 PSIA	±0.5 PSI	20 PSI/SEC	GH_2, 600°R, FLUSH MNT	3.1	6.1		
P-1C-TF	PRESSURE	7	3	0-20 PSIA	±0.5 PSI	20 PSI/SEC	AMB. AIR, MNT ON INLET DUCT STRUCT.	3.1	6.1		
P-2A-TF	PRESSURE	28	12	0-100 PSIA	±0.5 PSI	20 PSI/SEC	LUBE OIL, 1000°F, FLUSH MNT.	3.1	6.1	3.1	6.1
P-3A-TF	PRESSURE	7	3	0-200 PSIA	±0.5 PSI	20 PSI/SEC	HOT GAS, 2500°R, FLUSH MNT.	3.1	6.1		
P-3B-TF	PRESSURE	7	3	0-150 PSIA	± 2 PSI	20 PSI/SEC	HOT GAS, 2500°R, MNT IN EXH. DUCT	3.1	6.1		
P-3C-TF	PRESSURE	7	3	0-200 PSID	± 4 PSI	20 PSI/SEC	LH_2, 530°R, MNT ON VANE PUMP	3.1	6.1		
V-1	VIBRATION	15	24	0-5 g	±0.5 g	0-5000 Hz	BEARING: COMPRES., TURB., PUMP, APU CLUTCH PWR. TRN.			2.3 2.4 2.6	5.3 6.2
V-1A-TF	VIBRATION	21	9	0-5 g, 3-AXIS	±0.5 g	0-3000 Hz	BEARING: FRONT FAN, CORE, LO-PRES.	3.1	6.1	3.1	6.1
AC-1-TF	ACOUSTIC	7	3	30-160 dB	± 3 dB	50-10,000 Hz	MNT ON ENG. PWR. ASSY.			3.1	6.1

NOTES: TF = TURBOFAN
MNT = MOUNT